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N. E. COTTON MANUFACTURERS' ASSOCIATION.

PROCEEDINGS

OF THE

TWENTY-THIRD ANNUAL MEETING,

HELD AT BOSTON,

APRIL 25, 1888.

PRECEDED BY

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1888.

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1888.

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Herbert Fisher		Taunton, Mass.
M. F. Foster		Milford, N.H.
Philip H. Fowler	Gloucester Gingham Mills,	Gloucester, N.J.
Frank H. Fries		Salem, N.C.
William B. Gambrill	Druid Co.	Baltimore, Md.
William Gammell, Jr.	Berkeley Co.	Providence, R.I.
A. J. Gardiner	Danielsonville Cotton Co.	Danielsonville, Conn.
James G. Garland		Biddeford, Me.
Richard Garsed	Wingohocking Mills	Philadelphia, Penn.
James A. Gary	Alberton Cotton Mills	Baltimore, Md.
Charles J. Goodwin	Indian Orchard Mills	Indian Orchard, Mass.
Alfred M. Goodale	Boston Manuf. Co.	Waltham, Mass.
David Gowdey		Providence, R.I.
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Benjamin Greene	Cabot Manuf. Co.	Brunswick, Me.
Stephen Greene	Whitefield Mills	Newburyport, Mass.
William C. Greene	Thorndike Co.	Thorndike, Mass.
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Z. D. Hall		Lowell, Mass.
H. P. Hammett	Piedmont Manuf. Co.	Greenville, S.C.
J. F. Hanson	Bibb Manuf. Co.	Macon, Ga.
C. M. Harris, Jr.	Oakdale Shirt Manuf. Co.	Oakdale, Mass.
Frank Haskell	Westbrook Manuf. Co.	Saccarappa, Me.
William Hayes	Barker Mill	Auburn, Me.
Jefferson Higgins	Laurel Mills	Laurel, Md.
John H. Higgins	Forestdale Manuf. Co.	Slatersville, R.I.
J. G. Hill	Lawrence Manuf. Co.	Lowell, Mass.
J. P. Hillard	American Linen Co.	Fall River, Mass.
Charles H. Hobbs	Slatersville Manuf. Co.	Slatersville, R.I.
John Holland	Cocheco Manuf. Co.	Dover, N.H.
Stephen Holman		Holyoke, Mass.
George W. Holt, Jr.	Monohansett Manuf. Co.	Putnam, Conn.
William Hooper	Atlantic Cotton Mills	Boston, Mass.
John Hopkinson	Mississippi Mills	Wesson, Miss.
Elisha H. Howard	Harris Manuf. Co.	Providence, R.I.
Henry S. Howe		Boston, Mass.

David L. Jewell . .	China,Webs'r&Pemb'keM.	Suncook, N.H.
D. W. Johnson . . .	Monadnock Mills	Claremont, N.H.
D. J. Johnston . . .	Harmony Mills	Cohoes, N.Y.
Russell L. Jones . .	Ascutney Mills	Windsor, Vt.
Royal Kalloch . . .	Tennessee Manuf. Co. . .	Nashville, Tenn.
Roland R. Kelly . .	Wampanoag Mills . . .	Fall River, Mass.
Joseph H. Kendrick .	. . . . .	Providence, R. I.
Hervey Kent . . .	Exeter Manuf. Co. . . .	Exeter, N.H.
William J. Kent . .	Grinnell Manuf. Co. . .	New Bedford, Mass.
John Kilburn . . .	Lawrence Manuf. Co. . .	Lowell, Mass.
H. C. Kimball . . .	Blackstone Manuf. Co. .	Blackstone, Mass.
A. F. Knight . . .	Bozrahville Co.	Bozrahville, Conn.
Harold Lawton . .	Lapham's Mill	Centreville, R.I.
Frederick A. Leigh .	. . . . .	Boston, Mass.
Thomas I. Leiper . .	Irving & Leiper M'f'g Co.	Chester, Penn.
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Henry Lippitt . . .	Social Manuf. Co. . . .	Providence, R.I.
Henry F. Lippitt . .	Globe Mill	Providence, R.I.
Robert W. Lord . .	. . . . .	Kennebunk, Me.
Charles L. Lovering .	Whittenton Manuf. Co. .	Taunton, Mass.
Ernest Lovering . .	Lyman Mills	Holyoke, Mass.
Henry M. Lovering .	Whittenton Manuf. Co. .	Taunton, Mass.
William C. Lovering .	Whittenton Manuf. Co. .	Taunton, Mass.
J. S. Ludlam . . .	Merrimack Manuf. Co. .	Lowell, Mass.
Alvin S. Lyon . . .	Lowell Manuf. Co. . . .	Lowell, Mass.
W. H. Magee . . .	Berkeley Mill	Ashton, R.I.
Charles T. Main . .	Pacific Mills	Lawrence, Mass.
Charles H. Manning .	Amoskeag Manuf. Co. . .	Manchester, N.H.
Albert G. Martin . .	. . . . .	Petersburg, Va.
Rufus A. Maxfield .	. . . . .	Lowell, Mass.
Thomas Mayor . . .	. . . . .	Providence, R. I.
Robert McArthur . .	Pepperell & Laconia Cos.	Biddeford, Me.
W. E. McCoy . . .	Riverside Mills	Augusta, Ga.
Wm. H. McDavitt . .	Appleton Co.	Lowell, Mass.
Charles D. McDuffie .	Manchester Mills . . .	Manchester, N.H.
Fred. C. McDuffie . .	Everett Mill	Lawrence, Mass.
John Tempest Meets .	Godfrey S. P. Co. . . .	Taunton, Mass.
Frank M. Messenger .	Grosvenor Dale Co. . . .	North Grosvenor Dale, Conn.
James H. McMullan .	. . . . .	Biddeford, Me.

Timothy Merrick	Merrick Thread Co.	Holyoke, Mass.
Oliver H. Moulton	Hamilton Manuf. Co.	Lowell, Mass.
J. Turner Morehead		Leaksville, N.C.
W. H. Munroe	Thistle Mills	Ilchester, Md.
Franklin Nourse	York Manuf. Co.	Saco, Me.
E. H. Nutting	Hooksett Manuf. Co.	Hooksett, N.H.
Warren M. Oswell	Shirley Yarn Co.	Shirley, Mass.
John C. Palfrey	Manchester Mills	Boston, Mass.
Francis J. Parker	Monadnock Mills	Boston, Mass.
Walter E. Parker	Pacific Mills	Lawrence, Mass.
John H. Parks	NewBrunsw'kCottonMills,	St. John, N.B.
Theophilus Parsons	Lyman Mills	Boston, Mass.
William D. Pennell	Lincoln Mill	Lewiston, Me.
Haven C. Perham		Lowell, Mass.
John M. Pevey		Lowell, Mass.
Moses Pierce	Norwich Bleachery	Norwich, Conn.
H. L. Pratt	Bates Manuf. Co.	Lewiston, Me.
Thomas Pray, Jr.		Boston, Mass.
J. E. Prest		Whitinsville, Mass.
A. M. Pulsifer	Barker Mill	Auburn, Me.
J. M. Pusey	Delaware Mills	Wilmington, Del.
M. W. Quinn	Hamilton Woolen Co.	Amesbury, Mass.
T. G. Ramsdell	Monument Mills	Housatonic, Mass.
Robert Redford	Arlington Mills	Lawrence, Mass.
James Renfrew, Jr.	Renfrew Manuf. Co.	Adams, Mass.
Roscoe C. Reynolds		Lewiston, Me.
John Rhodes		Millbury, Mass.
F. H. Rice		W. Boylston, Mass.
Howard Richmond	Crompton Co.	Providence, R.I.
Charles A. Riley		Boston, Mass.
A. Robeson	Fall River Print Works	Brookline, Mass.
Louis Robeson	Appleton Co.	Boston, Mass.
William F. Salmon	Lowell Hosiery Co.	Lowell, Mass.
H. Saltonstall	Pacific Mills	Boston, Mass.
Wm. G. Saltonstall	York Manuf. Co.	Boston, Mass.
Eugene H. Sampson	Everett Mills	Boston, Mass.
Arnold B. Sanford	Globe Yarn Mill	Fall River, Mass.
J. H. Sawyer	Newmarket Manuf. Co.	Boston, Mass.

John Scott	Willimantic Linen Co. . .	Willimantic, Conn.
John C. Sharp, Jr. .	Canoe River Mills . . .	Taunton, Mass.
E. M. Shaw	Nashua Manuf. Co. . . .	Nashua, N.H.
Thomas S. Shaw . .	Suffolk Mills	Lowell, Mass.
Thomas C. Sheldon .	Sawyer Mill	Boylston, Mass.
George E. Sherman .	Valley Falls Co.	Valley Falls, R.I.
William F. Sherman .	Atlantic Cotton Mills . .	Lawrence, Mass.
Charles M. Shove . .	Granite Mills	Fall River, Mass.
Francis H. Silsbee . .	Pacific Mills	Lawrence, Mass.
James B. Siner . . .	. . . . .	Malden, Mass.
Arva C. Slater . . .	Linwood Mills	Whitinsville, Mass.
Robert R. Smith . .	Greenwoods Co.	New Hartford, Conn.
S. S. Spencer . . .	Conestoga Steam Mills .	Lancaster, Penn.
B. T. Stephenson . .	Waltham Bleachery . .	Waltham, Mass.
Wilbur A. Stiles . .	. . . . .	Newburyport, Mass.
Joseph Stone . . .	85 Milk St.	Boston, Mass.
Herman F. Straw . .	Amoskeag Manuf. Co. . .	Manchester, N.H.
Henry D. Sullivan .	Naumkeag S. Cotton Co. .	Salem, Mass.
James O. Sweet . .	Ashland Cotton Co. . . .	Jewett City, Conn.
Edward P. Taft . .	Ponemah Mills	Providence, R.I.
George P. Taylor . .	Lancaster Mills	Clinton, Mass.
Richard Thackeray .	Weetamoe Mills	Fall River, Mass.
E. A. Thissell . . .	. . . . .	Lowell, Mass.
Charles E. Thomas .	Clinton Manuf. Co. . . .	Woonsocket, R.I.
Edwin R. Thomas . .	Clinton Manuf. Co. . . .	Woonsocket, R.I.
E. W. Thomas . . .	Tremont and Suffolk Mills,	Lowell, Mass.
D. M. Thompson . .	Mills of R. B. & R. Knight,	Providence, R.I.
Osmon B. Tilton . .	Jackson Co.	Nashua, N.H.
William E. Trainer .	Linwood Mills	Linwood Sta., Penn.
C. H. Truesdell . .	. . . . .	Central Village, Conn.
Edmund E. Truesdell,	China,Webs'r&Pemb'keM.	Suncook, N.H.
James Waring . . .	Narragansett Mills . . .	Fall River, Mass.
John Waterman . .	Warren Manuf. Co. . . .	Warren, R.I.
J. W. Wattles . . .	. . . . .	Canton, Mass.
T. B. Wattles . . .	. . . . .	Suncook, N.H.
George W. Weeks .	Lancaster Mills	Clinton, Mass.
Henry F. West . . .	Washington Manuf. Co. .	Gloucester, N.J.
Channing Whitaker .	. . . . .	Lowell, Mass.
A. Tenny White . .	. . . . .	Biddeford, Me.
W. J. Whitehead . .	V.HudonCotton Manuf.Co.	Hochelaga, P.Q.
Charles E. Whitin . .	Whitin Manuf. Co. . . .	Whitinsville, Mass.
Harry T. Whitin . .	Rockdale Mill	Northbridge, Mass.

William H. Whitin	Whitin Manuf. Co.	Whitinsville, Mass.
A. N. Whiting	Whiting Mills	Oakdale, Mass.
William S. Whitney	Pocasset Manuf. Co.	Fall River, Mass.
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Thomas Wilmarth	Saunders' Cotton Mills	Saundersville, Mass.
George Wood	Millville Manuf. Co.	Philadelphia, Penn.
William B. Wood	Continental Mills	Boston, Mass.
C. J. H. Woodbury		Boston, Mass.
Daniel Wright	Moss Manuf. Co.	Westerly, R.I.

Total number of Honorary Members 2
Total number of Active Members 239

CALL FOR MEETING.

BOSTON, April 7, 1888.

DEAR SIR, — The stated Annual Meeting of the Association will be held at the Massachusetts Institute of Technology, Boylston Street, Boston, on Wednesday, April 25, at 10 o'clock A.M., for the choice of officers for the ensuing year, and the transaction of any other business which may properly come before it.

After the business of the meeting is concluded, Mr. WILLIAM F. DRAPER will give a RECORD OF TESTS OF POWER OF HIGH-SPEED SPINDLES WITH OILS OF DIFFERENT GRAVITY.

Mr. BENJAMIN A. DOBSON of Bolton, England, will present a paper upon PRINCIPLES OF CARDING COTTON, CARD WIRE AND CARDING ENGINES.

Mr. GEORGE ASHWORTH of Manchester, England, will speak upon CARD CLOTHING, AND FURTHER DEVELOPMENTS OF THE ASHWORTH CARD.

Mr. JAMES R. MAXWELL of Tuscaloosa, Ala., will explain a NEW SYSTEM OF PACKING COTTON IN SMALL BALES FOR SHIPMENT TO SPINNERS.

The three first-named papers will be printed in advance of the meeting, and a copy of either supplied to any member who applies for it to the Secretary.

By vote of the Board of Government,

AMBROSE EASTMAN,

Secretary.

PROCEEDINGS.

Pursuant to the foregoing notice the stated annual meeting of the New England Cotton Manufacturers' Association was held at the Massachusetts Institute of Technology on Wednesday, April 25, 1888. The meeting was called to order by President LUDLAM, and the call for the meeting was read.

The PRESIDENT. The Association has completed its twenty-third year. The first thing in order is the election of officers for the coming year. It is usual to appoint a nominating committee.

It was voted that the President appoint the committee, and he appointed Messrs. CHARLES D. MCDUFFIE, ROBERT MCARTHUR, WILLIAM C. LOVERING, HERVEY KENT and GEORGE W. WEEKS.

The PRESIDENT. I regret to announce to the Association that our Secretary, Mr. EASTMAN, is unable to attend in consequence of a sprained ankle. I will ask you to nominate a secretary to act in Mr. EASTMAN'S absence.

Mr. JAMES R. POWERS was chosen secretary *pro tem.*

The PRESIDENT. Mr. POWERS will now read the reports of the Secretary, Treasurer and Auditor.

The reports were read, and, upon motion, were severally accepted and ordered to be placed on file.

The PRESIDENT. The names of the following gentlemen have been presented to the Board of Government for membership in the Association, and have been acted upon favorably by the Board. They are now presented to you for confirmation.

Messrs.	Byron F. Card,	New Bedford, Mass.
	Alonzo A. Coburn,	Lowell, Mass.
	Andrew J. Currier,	Albion, R. I.
	Woodbury K. Dana,	Saccarappa, Me.
	Henry A. Davis,	Lowell, Mass.
	E. P. Dennis,	Lowell, Mass.
	Charles A. Denny,	Leicester, Mass.
	Frederick W. Ely,	Lowell, Mass.
	William Firth,	Boston, Mass.
	William B. Gray,	Boston, Mass.
	Ernest Lovering,	Holyoke, Mass.
	Charles E. Plummer,	Great Falls, N. H.
	Charles E. Riley,	Boston, Mass.
	Louis Robeson,	Boston, Mass.
	William E. Winsor,	Manchester, N. H.

By vote of the Association the above-named gentlemen were duly elected members.

The President. The first number on our programme seems to be the reading of a paper by Mr. William F. Draper, on the "Record of Tests of High-Speed Spindles with Oils of Different Gravity."

Mr. Draper. Mr. Chairman and gentlemen, before proceeding with the reading of the paper announced by your Board of Government, I wish to explain briefly the occasion for making these tests and the advantages to be derived from them if they are sustained by continuous practical experience, as I have no doubt they will be. My attention was first called to this matter of light oils for spindle-bearings by Mr. William E. Winsor, the agent at that time of the Amory Mills at Manchester, N. H. He had been making tests on rapid spindles with oils of different gravity, and reported to me very favorable results. The matter seemed to me important, and, being interested in the introduction of rapidly running spindles, I determined to make a series of tests for myself, to ascertain, in the

first place, if my results agreed with his, and, in the second place, to see if the same results followed with the different varieties of spindles. The Rabbeth spindle, as you know, has its bolster surrounded by a fibrous packing, in which it is peculiar and different from all other spindles that are run. I, therefore, made our tests with the Whitin spindle, which is a variety of the Rabbeth having no packing, and the results were similar and very satisfactory. The results of these experiments showed an average saving in power, by the use of lighter oils, of about fifteen per cent. I believe it is a usual estimate to call the cost of a horse-power forty dollars a year, including interest and depreciation of the plant. The results of a long series of experiments on spindles have shown that at a speed of nine thousand revolutions per minute not more than eighty spindles can be expected to be run by one horse-power on a medium number of yarns. That would make, using these figures, forty dollars a year for a horse-power and eighty spindles to a horse-power, a cost of fifty cents per spindle per annum for power. Fifteen per cent. of this saved is seven and one-half cents per spindle per annum. I was informed by the manager of the Nourse Mills that the whole cost of oil for his spinning room, including the oil used in oiling the spindles and the rolls and all the parts, was thirty-five hundredths of a cent per spindle per annum. Lighter oil costs more than the heavier oil, and, making due allowance for this, it is, perhaps, reasonable to call it a cent per spindle per annum, if the oil used in the Nourse Mills is a criterion. On this basis, if my figures are correct, the saving of power made by the use of the lighter oils is seven times the entire cost of the oil used in the spinning room, which seems to me a very important matter.

Besides this, I understand that the same advantages can be arrived at on mules and on fly-frame spindles, and on various other bearings in the mill where there is not great pressure, and where the parts oiled are in rapid revolution. If this discovery of Mr. Winsor were patentable, and were all it appears to be in results, I would undertake to introduce it among you

gentlemen within a reasonably short time, and to collect such a royalty on it that Mr. Winsor would receive a handsome income, and I would feel reasonably well paid for my trouble. As it is not patentable, but open to public use, I do not expect it will be so rapidly introduced. [Laughter.] You may laugh, gentlemen, but where one man has a special personal pecuniary interest in introducing an improvement, it is introduced more rapidly than it is where it is open to the public, and people take it up or not as they fancy. This matter, however, is so important that it seems to me it is worthy the making of tests by each of you, and if you discover the advantages which I think you will, I feel confident that the manufacturing industry of the United States will derive a benefit equal to the figures I have stated.

The paper is as follows: —

REPORT OF TESTS OF WHITIN GRAVITY SPINDLES MADE TO DETERMINE THE DIFFERENCE IN POWER REQUIRED TO DRIVE THEM WITH DIFFERENT LUBRICATING OILS. SAID TESTS WERE MADE AT THE NOURSE MILL, WOONSOCKET, R. I., BY MR. W. N. GODDARD, COMMENCING JAN. 10, 1888; MR. GEORGE O. DRAPER AND MR. F. W. STIMPSON PRESENT AND ASSISTING.

These tests form a part of a series of tests of different spindles at the same place. The Whitin spindle was selected, not because other spindles tested did not show favorable results, but because a complete series of tests was made with this spindle, and there has not been time to finish a similar series with either the Rabbeth or the Sherman.

The dynamometer used was built by Messrs. Fales & Jenks, and is the same that has been previously used by George Draper & Sons in testing spindles. Common sperm oil was used to lubricate the dynamometer. The thermometers and hydrometers used were made by Huddleston.

The temperature registered by a thermometer hung on the creel at the centre of the frame varied from 75° to 85°, and the relative humidity from 27° to 34°, during the actual time of making the tests. The gravity of the different oils was determined at the temperature of the oil in the tank in the spinning room, 74°.

The general method of testing was to test first with the bobbins about seven-eighths full, doffing when full, and then testing with the empty bobbin spinning; the mean of these two giving the number of spindles to one horse power while spinning. Then a test was made with the cylinder and spindles, only, running; which gave the number of bare spindles to one horse power.

When the tests of one kind of oil were completed, the top rolls were taken out and wiped; the oil removed from spindle bases with a syringe, and the base wiped out; the bolsters were cleaned in a steam jet, and the spindles wiped.

The usual times of making the tests were from ten to twelve o'clock in the forenoon, and from three to five o'clock in the afternoon.

The frame was one of sixty like it in the same room, which had been running since the mill was started, about three or four years since. It was made by the Whitin Machine Works, and contained 192 new Whitin spindles of the most recent pattern. The description of the frame in detail is as follows: —

Seven-inch cylinder, geared end, single boss top-rolls, double iron saddles, $2\frac{3}{4}$-inch gauge, $1\frac{3}{8}$-inch double ring, $5\frac{1}{2}$-inch traverse, no separators. It was spinning No. 40s. yarn from double roving.

The driving belt was $1\frac{7}{8}$ inches wide, and the frame pulleys were $10\frac{7}{8}$ inches diameter for the low speed, and $9\frac{13}{16}$ inches diameter for the high speed. The average number of revolutions per minute at the high speed were for the cylinder, 1,149; spindles, 9,491; front rolls, 103.8. At the low speed, cylinder, 1,039; spindles, 8,589, and front rolls, 93.8.

The spindles were carefully set concentric with the rings at the top and bottom of the traverse. Band tension averaged $1\frac{1}{2}$ pounds.

The oil in use in the room at the time was said to be "B" spindle oil from Seccomb, Kehew & Sons, costing thirteen cents a gallon, and of the gravity of 27.3. The first tests were made with this oil, and after the other oils had been tested this was tested a second time, with practically the same results as were obtained at the first test.

The spindles were first tested at the high speed; namely, 9,491 revolutions per minute. With the "B" oil five tests were made. The average of these tests gave these results: —

Spinning, ...	99.88 spindles to one horse power.
Cylinder and spindles only, . .	142.30 spindles to one horse power.

All the other oils were purchased from Frank L. Young, 32 Oliver Street, Boston, the next oil used being the Meriam & Morgan paraffine oil, gravity 26.3, cost fifteen cents per gallon. Three tests were made, averaging as follows:

Spinning, ...	100.12 spindles to one horse power.
Cylinder and spindles only, . .	145.17 spindles to one horse power.

Substantially the same result as with the other oil.

The next oil, known as "Climax," was of 34.4 gravity, and cost twenty-eight cents per gallon. The average result of two tests was as follows:

Spinning, ...	102.80 spindles to one horse power.
Cylinder and spindles only, . .	148.68 spindles to one horse power.

The next oil in gravity was a mixed oil, known as "Ultra-Sperm," the gravity being 36.2, and cost forty cents per gallon. The average of two tests showed:

Spinning, ...	111.6 spindles to one horse power.
Cylinder and spindles only, . .	169.23 spindles to one horse power.

The next oil, called "Acme," was of 38.2 gravity, and cost twenty-four cents per gallon. The average of two tests gave:

Spinning, ...	112.64 spindles to one horse power.
Cylinder and spindles only, . .	175.43 spindles to one horse power.

The same oils were tested with the spindles at the lower speed; namely, 8,589 revolutions per minute. The results were as follows:

"B" oil, average of three tests:

Spinning, ...	114.88 spindles to one horse power.
Cylinder and spindles only, . .	158.50 spindles to one horse power.

Paraffine, average of three tests:

Spinning, ...	111.80 spindles to one horse power.
Cylinder and spindles only, . .	151.64 spindles to one horse power.

Climax, average of two tests:

Spinning, ... 117.2 spindles to one horse power.
Cylinder and spindles only, . . 160.91 spindles to one horse power.

Ultra-Sperm, average of two tests:

Spinning, ... 130.84 spindles to one horse power.
Cylinder and spindles only, . . 190.65 spindles to one horse power.

Acme, average of two tests:

Spinning, ... 130.86 spindles to one horse power.
Cylinder and spindles only, . . 198.36 spindles to one horse power.

SUMMARY.

REVOLUTIONS PER MINUTE OF SPINDLE, 9,491.

OIL.	Gravity.	Spindles to One Horse Power. Spinning.	Spindles to One Horse Power. Rolls Stopped.
"B,"	27.3	99.88	142.30
Paraffine, ...	26.3	100.12	145.17
Climax, ...	34.4	102.80	148.68
Ultra-Sperm, ...	36.2	111.06	169.23
Acme, ...	38.2	112.64	175.43

REVOLUTIONS PER MINUTE OF SPINDLE, 8,589.

"B,"	27.3	114.88	158.50
Paraffine, ...	26.3	111.80	151.64
Climax, ...	34.4	117.02	160.91
Ultra-Sperm, ...	36.2	130.84	190.65
Acme, ...	38.2	130.86	198.36

From these summaries it is plain that the oils of lighter gravity enable the spindles to run with materially less power. The value of an oil as a lubricator is not always necessarily indicated by the gravity; as the so-called ultra-sperm oil was considered by the experts to be a more valuable oil than the one of lighter gravity, from the fact that it had greater viscosity, and greater durability, when used in oiling the rolls. This would also indicate greater durability in lubricating the spindles.

There is no question but that these results are exceedingly important to cotton spinners. The tests exceed in lightness anything ever made before to our knowledge with any spindles. Of course the frame was in good condition, the ring small, and the number of yarn comparatively fine. Judging from former tests, the difference in power between No. 28 print-cloth yarn with $1\frac{5}{8}$-inch ring, and the yarn spun at the Nourse mill with $1\frac{3}{8}$-inch ring, would not be far from fifteen per cent. Making this allowance, these spindles can be run on print-cloth yarns at a speed of 9,500 turns per minute with the lighter oils named, at about 95 spindles to the horse power; and on coarser yarns the same proportional advantage can be gained.

It seems to me that this is a matter of the greatest importance for consideration; and that, by the universal adoption of lighter oils in spinning, a saving amounting to hundreds of thousands of dollars per year can be made in the cost of power required to drive the spindles of the cotton mills of this country.

If any of you gentlemen would like to ask me any questions in regard to the detail of these tests, I think I can answer them.

Mr. Henry F. Lippitt. I should like to ask the gentleman if he can give us any data, or if he has any data, as to what the result would be with the other common forms of spindle, say the Sherman or the Rabbeth.

Mr. Draper. These tests were made on the Whitin spindles. We have made tests and are to make them with both

the Rabbeth and the Sherman spindles. With the Rabbeth spindle we attained results somewhat lighter even than these. The question of power between the various kinds of spindles was something I did not intend to go into, but I can say briefly that there is no magic in the matter. With any spindle where its bearings are arranged so as to prevent gyration, with an equal band pull, and the same oil, and the same fit of the spindle and its bearings, the question of power depends upon the diameter of its bearings. The Rabbeth spindle has bearings of a somewhat smaller diameter, and we expected it, and it has proved in practice, to show a power about in proportion to the diameter of its bolster bearing. In this case the diameter of the bolster bearing is eight per cent. less than the Whitin, and the advantage we discovered in power with one of these oils was about eight per cent. We have not gone through with all the oils, so I cannot state that it would be verified all the way through.

There was another matter, if I am not trespassing upon your time, of some interest that I will mention, although it is not directly connected with running the spindles, and that is with regard to the fit of the spindles in their bearings. We put in two sets of spindles substantially alike, with the same band pull, and tested them to see if different sets of spindles would require the same power. To our surprise we found a difference of some thirteen or fourteen per cent. between one set of spindles and the other. We looked them over carefully to find what the difficulty was. The frame was exactly the same, the bands were the same, the spindles were put inside the same bands, the oil was the same, but we discovered by accurate measurement that there was a difference in average fit of the spindles in their bearings. The one that had the larger bearing required the less power. We then very carefully rimmed out the bearings of the second set of spindles, so as to bring the fit to the same average right through, and the difference in power was eliminated, showing that there is a difference between a reasonably tightly fitting spindle and what is

considered a loose fit for a spindle, at least in that case, of some thirteen or fourteen per cent. in power. Of course, it may not be desirable for you to buy spindles with two or three years' wear out of them, but I have no doubt, if it has not gone to a point where the spindles vibrate, you will derive the advantage in power of which I speak.

Mr. LIPPITT. I will ask the gentleman if these light oils were pure mineral oils or a mixture.

Mr. DRAPER. As I understand it, they were all pure mineral oils, with the exception of this oil which was marked "Ultra-Sperm." I will say further with regard to this, that while these oils were obtained from one dealer, I have no doubt similar results can be obtained with oils of the same gravity. I consider that the difference of gravity in the oil is what affects the result. Mr. Woodbury tells me that the "B" oil which was used was a mixed oil, and not an entirely mineral oil.

Mr. WOODBURY. I would like to ask the speaker if he recommends the use of as light oils as thirty-eight gravity on the rolls.

Mr. DRAPER. My idea of it is that it would be better to use an oil of heavier gravity on the rolls than on the spindles, but, as I was informed in the mill, it was considered more desirable to oil the rolls with the same oil as the spindles, for practical reasons. They desire to have only one kind of oil in the room. I think the rolls require an oil of greater viscosity than the spindles.

A MEMBER. Will the gentleman please tell us how often he would have to oil his spindles with a thirty-eight gravity oil compared with the twenty-seven "B" oil?

Mr. DRAPER. That is a question I am unable to reply to, as these oils were tested for only a short time, and then pumped out and the bases cleaned. That is a matter which can be ascertained by further experiments. I think Mr. Goddard, who made the tests, is present, and perhaps he can tell how long any of the oils run.

Mr. GODDARD. The exact time the spindles run was comparatively short, not over a week.

Mr. DRAPER. There was no difficulty in running that length of time with any of the oils?

Mr. GODDARD. Not at all.

A MEMBER. Why would you recommend one oil for the rolls and another for the spindles?

Mr. DRAPER. My idea is this, that in the spindles the oils cannot escape, while on the rolls a lighter oil can run off and escape; and, as I understand it, it has been customary in many places to use a heavier oil on the rolls and a lighter oil on the spindles.

Mr. MCARTHUR. I would like to ask Mr. Draper how he treated the Rabbeth spindles.

Mr. DRAPER. Mr. Goddard will explain what was done.

Mr. GODDARD. "The oil was removed from the spindle bases with a syringe,"—perhaps I cannot state it better than to read from the paper,—"and the base wiped out," with ordinary cotton waste; "the bolsters were cleaned in a steam jet and the spindles wiped."

Mr. DRAPER. Such oil as remained in the packing still remained?

Mr. GODDARD. In one case the packings were taken out of both.

Mr. MCARTHUR. In a test in our mill we pumped the oil out as well as we could with a syringe, and we made a gain of about eight per cent.

Mr. DRAPER. I don't know whether Mr. Winsor is here, but I have been informed—this is something I did not see myself—that, using an Emerson power scale, he would pour into the bases of the Rabbeth spindles, simply letting the oil mix with the oil that was there before, a lighter oil, and it would immediately show several spindles to the horse-power on the scale. I am not stating this as something I have seen, but as something which was told to me as the fact.

The PRESIDENT. If no other gentleman would like to asl Mr. DRAPER any further questions, the committee to nominat officers is ready to report.

Mr. McDUFFIE. The committee appointed to nominat officers for the ensuing year reports as follows: —

PRESIDENT.

HENRY F. LIPPITT, ...	Providence, R. I.

VICE-PRESIDENTS.

WALTER E. PARKER, . . .	Lawrence, Mass.
ARNOLD B. SANFORD, . . .	Fall River, Mass.

DIRECTORS.

ROBERT McARTHUR, . . .	Biddeford, Me.
O. S. BROWN, ...	Salmon Falls, N. H.
STEPHEN N. BOURNE, . . .	Manchester, N. H.
S. S. SPENCER, ...	Lancaster, Penn.
E. W. THOMAS, ...	Lowell, Mass.
WILLIAM H. WHITIN, . . .	Whitinsville, Mass.

The PRESIDENT. I believe it is incumbent upon us, by ou by-laws, to elect officers by ballot, but it has sometimes bee done by the meeting instructing the Secretary to cast one bal lot. Will some gentleman make such a motion?

Mr. WOODBURY. I move that the acting Secretary be in structed to cast a ballot for the list of officers as reported b the committee. Adopted.

The Secretary cast the ballot as directed, and the officer were declared elected as reported by the committee.

Mr. HENRY F. LIPPITT, the newly elected President, there upon assumed the chair.

Mr. A. G. CUMNOCK. I move that a vote of thanks be ex tended to Mr. DRAPER for his paper and experiments; and tha he be recommended to continue experiments on the Rabbeth an Sherman spindles, and present the report at the next meeting

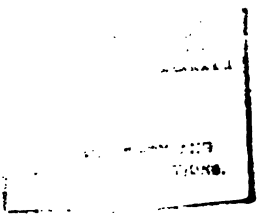
Mr. JOHNSTON. I would add that he also make experiments on spindles that have no receptacle to hold the oil, — like mule spindles and the old fashioned spindles, — and give us at the same time the result of the wear and tear.

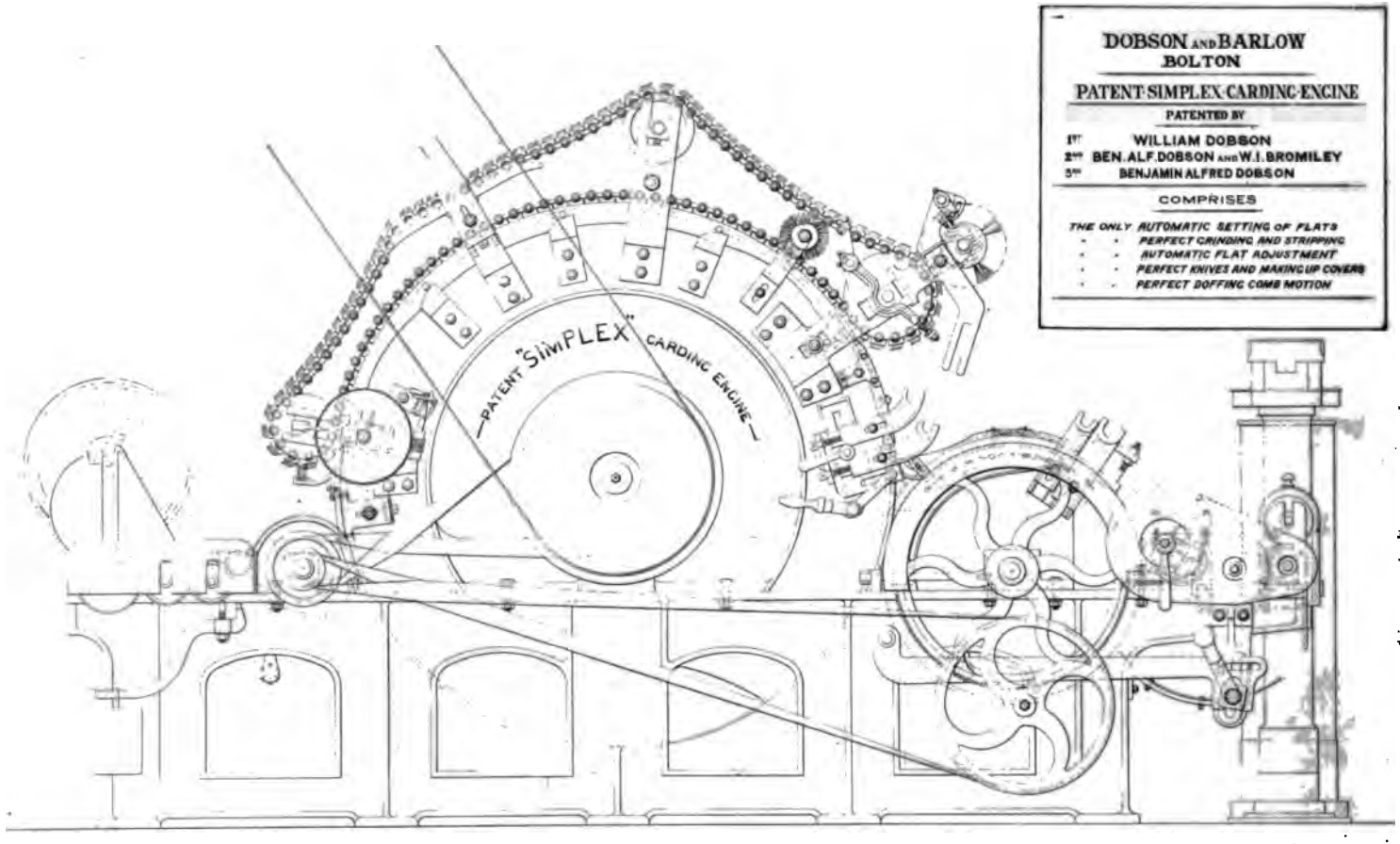
Mr. CUMNOCK. I accept the amendment.

The motion was adopted.

Mr. THISSELL. Before this subject is left, inasmuch as Mr. Winsor's name has been mentioned in reference to the advantages of different gravities of oils used for lubrication, I would like to say that Mr. Winsor followed up the experiments which were begun at the Amory Mills before he went there. Mr. Winsor wrote me a letter in which he said that at first he found he was getting with a twenty-eight gravity oil sixty spindles to a horse-power. He then used a lighter gravity oil, and that carried him from sixty-eight to seventy. Then he ordered a thirty-five gravity oil, that gave him from eighty-four to eighty-eight. He saw he was on the right track, and asked for an oil which was thirty-eight gravity, providing it would stand the fire test. That oil gave him one hundred spindles to the horse-power. He wrote me in his letter that his experiments had saved him thirty per cent. of the power in his spinning room, and sixty-six per cent. on the bands. The lighting up of the spindles saved the wear and tear of the bands and made a great saving in wear and tear of machinery. Any gentleman can make these tests for himself. These tests were made by the overseer with the Emerson Power Scale, and it does not require an expert to do it. A second hand can make them. The advantage does not stop in the spinning room. I see some of the gentlemen laughing, and, as Mr. Draper says, it is the patented article that sells and makes progress. Now, the same difficulty exists in the wear and tear and the friction of machinery all through the mill. And while some people are saving considerable by guess, they will find that if they use an Emerson Power Scale on the main lines of shafting, where they can see the amount of power they are using, large savings can be made daily.

The PRESIDENT. The next event on our programme is Mr. DOBSON'S paper upon the "PRINCIPLES OF CARDING COTTON, CARD WIRE AND CARDING ENGINES." I have the honor to introduce to you Mr. BENJAMIN ALFRED DOBSON, a member of the well-known firm of DOBSON & BARLOW of Bolton, England.

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THE ONLY AUTOMATIC SETTING OF FLATS
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" " PERFECT KNIVES AND MAKING UP COVERS
" " PERFECT DOFFING COMB MOTION
PATENT "SIMPLEX" CARDING ENGINE

Principles of Carding Cotton, Card Wire and Carding Engines.

By Benjamin Alfred Dobson, Bolton, England.

[When I selected the subject for the paper I am about to read, I was unaware of the fact that it had already been discussed more than once by your society. As the question is still of leading importance in England and America, I venture to hope that the paper may not prove uninteresting, and that there may be drawn from it some useful practical results.

I have endeavored to avoid making invidious comparisons or personal references.

April, 1888. B. A. D.]

In the primitive days of cotton spinning the operation of preparing the cotton for the various processes of spinning was of the most elementary description. The cotton when taken from the bales was laid upon a table of open lattice work and beaten with a stick which was known in England as the "batting stick." This shook out the heavy dirt which fell through the interstices, and softened and opened the flakes of cotton sufficiently to allow of the next operation, a species of carding. This was performed by a series of cards fastened on a table or bench. The cotton was lightly spread with the fingers, the operative then taking a card mounted on a small board to which was affixed a handle, and by rapidly and carefully drawing this over the surface of the underneath cards succeeded in paralleling and stretching the cotton. This was done for a certain time, in the judgment of the operative sufficient, and then it was removed from the cards and taken off in the shape of a "fleece" with what was then termed a "needle stick." In this operation a certain amount of the fly and dirt remained in the interstices of the card wire, and both the lower wire and the upper wire required occasional cleaning with the "needle stick."

When later on the development of the trade required this to be done more regularly and mechanically, and above all, continuously, two individuals took out patents for this purpose, viz., Lewis Paul and Bourn. This card was introduced into the cotton-spinning districts of Lancashire in the year 1760, and a further improvement was added by Sir Richard Arkwright, who introduced, amongst many other improvements, the doffing comb. From the very first, two distinct ideas with regard to the detail of the machine were developed, Bourn having plainly shown the principle of the roller card and Paul the fixed flat card system; and some of the cards which were made at the end of the last century, and which worked up to a few years ago at Sir Richard Arkwright's establishment in Cromford, have the lap roller, feed rollers, fixed flats, doffer and doffing comb, almost identical in principle with cards made at the present day. It will be seen at once what an immense stride as regards practical industry was made when the old hand system was supplanted by a mechanical system which gave a continuous card sliver; and this problem once being solved left free course open to inventors to further improve and vary the details of this machine. The number of models of improvements in cards that have been made is legion. The writer's own firm at one time had no less than 350 different patterns of card bends. Of course of late years the tendency has been to simplify the classification of the cards destined for various growths of cotton and qualities of work. It would be interesting, did time allow, to follow the variation of rollers, clearers and flats from the time of Paul and Bourn up to the present day, but it will suffice to say that the three important classifications of carding engines may be stated to be: first, the roller cards; secondly, mixed cards, containing rollers and flats; and thirdly, flat cards, either revolving or fixed. Each of these classifications has been subject to innumerable variations; for instance, some roller cards have all rollers acting simply as revolving flats, they being rollers turning slowly on their own centres and either periodically stripped by hand or

automatically stripped by comb, the ordinary roller and clearer card having an innumerable variety of detail as regards diameter of rollers and clearers, number of the same, and the speed; the mixed or composition cards with rollers and flats, some of the old-time cards having as few as 8 fixed flats, the remaining working surface being covered with rollers and clearers, down to the approved mixed card of the present day, containing 1 dirt roller, 2 rollers and 2 clearers and 20 flats; and the fixed flat card with the various widths ranging from 3 inches down to 1¾ inches; and lastly the card that seems to be the favorite of the present day, the revolving flat card with its flats varying from 2¼ inches down to 1⅜ inches. Of course it must be admitted that any variation in the detail of carding machines must to a certain extent affect the production or quality of the work done by this machine, and, nevertheless, it is sometimes very embarrassing to decide as to whether an alteration is really an improvement or otherwise, but it is always safer in judging of these points to consider the principle that underlies the working of the machines and the operation they are intended to effect. I would, therefore, propose, with a view to placing on record the result of considerable thought and study of this subject, a theory of carding which, though it may be deficient in detail, will, I think, be found reasonable and comprehensible.

For some reason the operation that the cotton is submitted to in the process of carding has generally been considered to be a sort of mystery, inasmuch as it is impossible to see the absolute action of the various organs of the machine when at work; and persons have written and talked about "films" of cotton and "layers" of cotton being operated upon, and this incorrectness of expression has given rise to ideas entirely mistaken as to the real nature of the process. But there really should be no difficulty in tracing from the feed roller of the card to the doffing comb the various alterations of condition that the cotton is subjected to. Starting with the feed rollers, I may say that in the opinion of most practical men in Lan-

cashire and the continent, — where, certainly, carding has been very carefully and ably studied, — the two greatest improvements that have assisted to increase the production of a card are the dish feed, or "Bodmer's" feed, as it was originally called, and the licker-in or taker-in, covered with what is termed inserted saw-tooth wire. These two parts of the card are not novel, both having been known for some thirty-five years and more; but having been badly made and improperly understood, their application in former years to cards working good cotton were considered to be, and were really practically, more injurious to the staple than anything else about the machine. At one time the idea was generally prevalent that it was impossible to card a good class of cotton with the dish feed and licker-in saw-tooth wire. It was imagined that the action on the cotton would be too rough and brutal, and that a loss of strength would certainly ensue. Now, it is undoubted, that with these two organs either ill-arranged or ill-adjusted it is quite possible to cut the fibre into pieces; but, with reasonable care, the action is no more injurious than the licker-in covered with ordinary wire, or the cylinder taking the cotton direct from the feed rollers, and the great advantage of it is that it allows, by altering the shape of the dish feed nose, a variation of the action, according to the length of staple employed. It must not be forgotten that all operations upon the cotton in a spinning mill have a more or less injurious effect upon the natural strength of the fibre, and the object of every one should be to arrive at the intended effect with the least possible amount of damage. The effect of the licker-in covered with saw-tooth wire, as compared with the old licker-in covered with sheets, is that the ordinary wire was incapable of striking down the heavy dirt with the same ease and certainty that it is now done. The licker-in soon got choked, it required constant stripping and grinding, and made more "neps" than in any other portion of a carding engine. You are all aware that the saw-tooth licker-in, when once properly made, never requires grinding and is always perfectly clean; if it is not, it is through some

defect in manufacture. The teeth of the licker-in strike through a certain portion of the thickness of the lap of the cotton, so that it may be said that the heavy dirt is struck through the lower side of the lap, previous to the cotton being released for the licker-in to seize hold and convey the fibres to the cylinder. This has eased the work of the carding engine a very great deal, and has, more than anything else, contributed to the great productions that have been arrived at of late years. In diagram No. 1 are shown four sections of feed dish noses for Indian cotton and waste, American cotton, Egyptian cotton and long Sea Island; and, comparing the sections, it will be readily seen how different the conditions are under which the licker-in teeth work, as regards the cotton lap produced by the action of the feed roller, and how the varying lengths of fibre are provided for, in order to prevent damage to the staple.

Well, now for the theory of carding. I do not know whether any of you gentlemen have ever tried the effect of running a carding engine at a very low speed, say for instance, instead of running the cylinder 160 to 180 revolutions per minute, running it at 20 or 30, but if any one has done this he will have found that there was a very slight practical difference in the quality of the carding. This may be noticed every day in any cotton-spinning mill when cards are stopped by the strap being thrown on the loose pulley. If the cards are properly constructed they can be stopped and started without any apparent difference in the "web" or in the cotton coming off sufficient to show when the difference of speed was made. This would seem difficult to understand if it were not for an examination of the speeds of the various portions of the machine. For instance, in the example of a revolving flat carding engine carding Egyptian cotton at about eight pounds per hour, the feed roller being 1, the licker-in would be 1,733, the cylinder 3,608, the doffer 132. Now, the cotton coming over the surface of the dish feed, and being worked by

the licker-in, the projecting ends are straightened to a very considerable extent, as may be seen any time by stopping the feed and pulling the lap back for examination. Diagram No. 26 shows this clearly.

It will be found that the lap if tolerably regular itself has the ends combed out and tapered from the full thickness of the lap to the thickness of a few fibres, and appears almost clean in that portion that has already been operated upon by the licker-in. As the cotton is fed forward by the feed roller, the points of the licker-in teeth seize hold of these fibres that are sufficiently liberated and carry them round past the dirt knives and the undercasing to the point of contact of the cylinder and licker-in. In this passage much good work may be done, nearly all leaf can be extracted, and dead cotton shaken out, and this with little or no fatigue to the staple. In some continental countries practical managers consider this of so much importance that by preference they personally do the setting of the knives and undercasing. I have no doubt but that these knives and undercasings improperly constructed and regulated will account for dirty carding and excessive waste. The angles of the knives and bars in the undercasing, the distance from one to another, and the distance between the points of licker-in teeth and the knives and bars are of great importance, and require adjusting to the requirements of the staple of the cotton being used.

Diagram No. 1 shows the various parts, the angles and distances being approximately correct for American cotton. Although there are as many points of wire on the surface of the licker-in passing any given point at any moment as there are fibres of cotton to be worked at that particular point, it will be readily understood that it is not possible for each point to take its particular fibre of cotton, and this can be practically seen by examining the conditions of the tufts of cotton which come off the licker-in when the undercasing is removed. These tufts consist of aggregations of an undetermined number of

fibres, the numbers being determined by varying conditions of the setting, the number of points, and the shape of the points of the licker-in teeth and the quality of the opening of the cotton in the lap, and lastly the speed of the licker-in. This being so and these tufts being carried round to the point of contact with the cylinder, we can understand that as the cylinder has a surface speed more than twice that of the licker-in, and that the number of points of wire passing in a certain time is as 27 to 1, that these fibres presented in tufts will not be taken away in the same condition, but will be taken to a certain degree one after the other. They are presented in a dishevelled condition to the action of the cylinder wire, and each fibre being tolerably free to part from its companions, and being seized by one of the points of the cylinder wire, will go away freely and thereby equalize on the surface of the cylinder the number of fibres in a given space. For instance, the number of points of cylinder card wire passing a given point in the circumference in a minute will be somewhere about 362,-000,000, and the points of the licker-in passing any point of the circumference are about 13,750,000 per minute, and the number of fibres fed in one minute 13,750,000. Now, it will be evident that the cotton coming from the feed part having been taken away by the licker-in and presented to the cylinder, and as it is taken in detail as far as practicable by the cylinder, it will be to an extent stretched and parallelized, and this simply owing to the difference of circumferential speed together with the difference of the number of points of teeth of the two organs, and that it will be fairly equally distributed on the working surface and that it will have lost a certain amount of its heavy dirt and leaf, but it is still curled and twisted and the short cotton or fibre is still with it and there is also the "nep."

Now, then, comes in the action of cleaning, the organs for which, as before explained, may be rollers and clearers, or flats, and as the cylinder in passing from the licker-in to the doffer has to carry its cotton past these cleaning organs, if there

should be any great irregularity in the aggregations of the cotton fibres these flats or other organs will seize the superabundant fibres and retain them for a certain time. This time depends upon the length of the fibre. The long fibres are naturally held more securely by the cylinder and less securely by the flats than the short fibres, and, in fact, when once very short fibres have been presented to the flats the cylinder is incapable of taking them back again, and this is one of the most valuable effects which render possible the cleaning of cotton in the card; but this condition is dependent upon the wire of the cylinder and flats being both in proper order. Now, the further equalizing process, and one which tends to parallelize the fibres coming from the card, is the giving of the cotton by the cylinder to the doffer. Now, as you are aware, the doffer is clothed with wire finer than the cylinder. Where the cylinder is 130 to the inch the doffer will be 140, the object of this difference being to give the doffer more points to seize the fibres presented by the cylinder, and it will be further seen that on the same principle of difference of circumferential speed, but reversed, by which the cylinder and licker-in have equalized the numbers of fibres in a given surface by exceeding the speed of the feed organ, that the doffer, by running slower than the cylinder, further increases this equalization, by, as it may be said, condensing the areas of variation, this particular operation practically being the same as the doubling of the further processes in a cotton mill. Now, the doffer on receiving the cotton on its surface from the cylinder, and turning at, say a speed of 132 to the feed roller one, is, by reason of the knife of the undercasing, which, as can be seen by diagram No. 4, is passed as far between the cylinder and doffer as possible, cut off from any further interference by the cylinder, and presents its cotton to the doffing comb without any further change. This particular action of a carding engine is often spoken of by old card overlookers as the best carding point of the machine, and upon the accuracy of

the surface of the doffer wire, the closeness of the setting to the cylinder, and the state of the teeth of the doffer wire, depends the equality and smoothness of the web taken off by the comb. Now, the taking of the web through the condenser plate and callender rollers or draw-box to the coiler are absolutely identical in all cards, and require no explanation. I give here a table showing the particulars of the figures from which I have quoted. This table is taken from a paper I read before the Bolton Mill Managers' Technical Association in April, 1886:—

Carding Engine Working Egyptian Cotton. — Single Carding for 60s Twist.

Name of Working Part.	Revolutions per Minute.	Diameter in Inches.	Circumferential Speed in Inches.	Proportionate Speed.	Nos. of Wire Clothing.	No. of Points of Wire on 1 In. x 40 Inches.	Area of Working Part in Sq. Ins.	No. of Points on Working Parts.	No. of Points at Work.	No. of Fibres on Working Parts.	Fibres on 1 In. x 40 Inches.	Waste per Cent.
Feed Roller, . .	1	2¼	7·068	1	–	–	–	–	–	–	1950066	0·6
Licker-in, . .	400	9¾	12252	1733	8	1120	680	34305·6	19040	18819	1107	1·6
Cylinder, . .	160	50¾	25504	3608	120	24000	3760	3825600	2256000	49791	529·7	·41
Doffer, . . .	12	24¾	933	132	130	29000	1760	2254750	1276000	605176	13754	–
110 Revolving Flats,	–	–	3·75	0·53	130	29000	1760	3190000	1276000			3·3
8 Stationary Flats,	–	–	–	–	100	21000	400	210000	210000	–	–	3·0
8 " "	–	–	–	–	110	23000	400	230000	230000			
8 " "	–	–	–	–	120	27040	400	270400	270400			
8 " "	–	–	–	–	140	28000	400	280000	280000			
Doffing Comb, .	1137	8¼	29472·6	4208	–	–	45	660	660	–	–	–

It may further assist if I state that in taking the ordinary Egyptian cotton as carded in a Bolton mill for No. 60s, the weight of lap per yard is 10 ounces, the speeds of the various organs as per the foregoing table, the waste to the licker-in as 2 per cent., the waste of the cylinder as one-half per cent., and that on the flats as $3\frac{1}{2}$ per cent. The compressed thickness of the lap may be taken as about the forty-seventh part of an inch, and the thickness of the layer of cotton on the various organs of the card would be: On licker-in $\frac{1}{81.471}$ inch; on cylinder $\frac{1}{169.576}$ inch; on doffer $\frac{1}{6.204}$ inch. The thickness of fibre of ordinary Egyptian cotton is the 1.1526 part of an inch, which will show that the cotton on the working part of the card is not a continuous web, film or layer as you hear too often talked about when carding is being discussed, but consists of fibres and aggregations of fibres with relatively large spaces. The extent of space of the working surface, as compared with the surface of cotton, is for the licker-in as 23.5 to 1, for the cylinder as 50.8 to 1, and for the doffer as 1.86 to 1. It will be seen, therefore, that the licker-in has a few more points of wire than there are fibres on the licker-in at any time. The cylinder has at least four times as many points of wire as there are fibres, and the doffer over twice as many, and that in 110 revolving flats, of which 44 are constantly at work, there are eight times as many points of wire as there are fibres of cotton on the flats. Now, from the foregoing remarks it will be seen that some of the existing ideas of the action of carding must necessarily have been founded on a want of knowledge of the actual conditions, and that no doubt much misconception has arisen, owing to the belief that there was always a large amount of cotton between the cylinder and the flats or rollers actually under operation.

The effect of centrifugal force on carding (as an assistant) has also been very much exaggerated. No doubt centrifugal force does aid to a certain extent, but not to anything like the degree generally attributed to it. This can be proved, as I have said before, by slowing the card to an absurdly

slow speed, and observing the work. This naturally brings up the question of what is really the action of the card wire upon the cotton, and this point has caused so much contention that it has been with some diffidence that I have ventured to include it within the scope of my remarks; but having been forced by circumstances to discuss this question with many individuals, I have to a certain degree formed conclusions. It may be said that in carding, as in most other things, there are two extremes, and between these will range the gradations. In the first place there is quality, and in the second place quantity. If quality alone is wanted, irrespective of the question of production, the same conditions do not hold good, and the same applies exactly as regards quantity. I maintain that it is impossible to get at the same time the extreme of quality and the extreme of quantity, and that as one increases the other suffers. In fact, this is an axiom or principle that is universally applicable, not only to carding but to almost everything else. It is then more a matter for the spinner to decide as to whether the result is satisfactory to him or not, and if he prefers quantity it is an easy matter to arrange to have this quantity. If I were asked to enunciate the guiding principles for the clothing of carding engines, I should say, first of all, the licker-in should be clothed with inserted wire as smooth as it can be made and as hard as it can be made; that there should be no variation in the heights of the points from the centre of the licker-in, and that the angle of the tooth should be carefully calculated for the quality of the cotton and the speed of licker-in desired; that the cylinder should be clothed with a wire set in a foundation sufficiently strong to stand the stretching on the cylinder without deforming the angle of the wire or laying any extra stress upon any portion of the wire, and stand also the strain of grinding; that the angle of the lower part of the bend should be such that there would be no danger of the wire at any time rising so as to come into contact with the wire of any other organ, and so that the wire should hold well up to the grinding; that the whole of the lower portion of the wire from the extreme upper

point may be smooth as possible, — as smooth as the card maker knows how to manufacture it; that the points should not be what is termed "open set," but should by preference be twilled set, so that in looking across the card there should be as unbroken a front of wire points to the view as possible, and that it should not be practicable for any length of straight open space between the wire to exist. What I have said previously with regard to the number of fibres that are in operation at any one time will show the importance of this. The wire may be made of either iron or steel. Iron wire, thoroughly, well and carefully ground and set will give a point suitable for carding that can be excelled by nothing. I feel inclined to place mild steel wire on the same level as the best iron wire, inasmuch as its homogeneous nature allows a very careful and exact grinding, and the point formed on this wire is little if at all inferior to that of the iron wire. Top ground hardened and tempered wire has of late years come into favor for carding good qualities of cotton, where some time ago it was looked upon with disfavor. The difference of the point formed on the wire by good or bad grinding is very easy of understanding. If the grinding be slowly, lightly and carefully done, the front edges of the points, which are formed by grinding backwards, are serrated by the action of the emery, and these serrations are as numerous and fine as the nature of the metal will permit. If done hastily and heavily, the serrations are coarser, and often the pressure and heat combined cause the metal to "flow" over and cause what is generally termed "hook." This is very prejudicial to the quality of carding and increases the waste. Keeping in view the object to be attained, viz., to procure the greatest number of serrations of the extreme top surface of each point of wire, it will be evident that the quality of the metal governs this, and practically the serrations formed on the upper surface of hardened and tempered steel, although not so acute and fine as that on softer metal, are for the coarser fibres of cotton sufficiently so to practically perform the work required. The dif-

ference in the serrations comes from the distinction betwee fibrous and granular metals.

The object of the wire maker and the carder who sets an grinds his cards should be to take the cotton round from th back of the card to the front with as little damage and fatigu to the fibre as possible; at the same time that the cleanin should be as effective as possible, and that, when it is neces sary to brush or strip the cylinder or flats, this operation shoul be done with as little fatigue to the wire and brush as possible Furthermore, the character of the foundation of the wir should be such that when once put on it will not change it nature from variations in temperature or moisture of the at mosphere. For the doffer, I may say almost exactly the sam as I have for the cylinder. The wire should be finer. I should be top ground only and should be twill set so as t present to the cylinder the greatest front of wire possible. A card covered with the wire I have just named will do proportionately to quality more than any other description of clothing, and the cotton coming off in a "web" at the front wil have the fibres more parallel and require less drawing afterwards, and will consequently give smoother yarn and also a stronger yarn. This can often be seen in making comparisons in the first drawing head and even in the sliver itself from the card. You will see that I have contended on the principle o top grinding and twill setting. This will at once bring me into conflict with a large number of people who are believers in exactly the opposite, viz., what is termed "needle-pointed" or "side-ground" wire, open set. I may say at once that the "open set" is necessary for the production of the "side-ground needle-point," as otherwise its manufacture would be impossible, and I presume, therefore, that making a virtue of necessity the manufacturers of the "needle-pointed wire" profess to believe that the "open set" is preferable. It is better in carding to have a point which only has a serration caused by grinding the extreme top, and by this means cleaner and smoother carding can be got, from the fact that on both cylin-

der and flats the points that really hold the cotton are closer together, and I am also of opinion that the fibre itself is less injured in the process of carding with this point than by the so-called needle-point. It will perhaps be said, How can you explain the fact that the needle-pointed wire has been so successful in so many cases, that it is producing such great weight and that there is so much satisfaction expressed with its working? and I may be asked also, Have you not yourself seen cards clothed with this wire working in a satisfactory manner? I may say at once that when I first saw the needle-pointed wire I was extremely astonished at its apparently good work, and to find a wire made on principles so opposed to what one's education had allowed him to believe was the correct principle, and it was not until after much study and for a considerable time that the mystery was solved.

In the first place, many of these cards have replaced wire of an old manufacture which was at all times incapable of producing the weights of the present day; most of these cards have had the saw-tooth licker-in and dish feed applied either before or simultaneously with the hardened and tempered clothing, and of course the cards are working under different conditions; but to explain the apparent paradox of the difference between the needle-pointed wire and the top-ground wire is simpler than it would at first seem. The fact is, that all side-ground wire, whether on one system or another, whether the "chisel" point or the "needle" point, is roughened a certain distance down from the top, and the result is that it gives the wire greater holding power than would seem possible; that is to say, that instead of the fibres of cotton being seized by the point of the wire and taken round between the flats and the cylinder for the purpose of cleaning and straightening, they may adhere to a portion of the wire some distance below the point, and the result of this is to depreciate the straightening process. There is another point with regard to this wire. It will make less waste undoubtedly from the fact that there is more room for the cotton to get out, and that through the fact of there being a

space which decreases inwards as the depth increases, it naturally tends by side grinding, together with the roughness thereby caused, to prevent any fly or waste from sinking below a certain depth. I have myself on many occasions examined these cards and found a layer or film of fly a certain distance from the top of the wire, and always about the same thickness, which did not seem to increase much with running, and very soon after the card was cleaned the film was formed again. The reason that this film of short cotton does not sink lower than a certain level is, as I said, on account of the tapered space and the roughness of the side-ground wire; but inasmuch as all cotton has a certain quantity of fly which produces waste, it is evident that if one card makes less waste than another, that card which makes the most waste must be taking out long fibres that it should not, or that card making the least waste is sending fly with the cotton which will ultimately make dirty spinning rooms and dirty yarn. The film when once formed acts as a partition which prevents further deposit, and the fly which would naturally be left in the cylinder wire is forced to accompany the long fibre. It would then, if it could, attach itself to the wire of the flats, but as these are already sufficiently charged the good cotton places it on the doffer wire. The result of this is that there is a considerable change in the composition of the "web" between, the wire being thoroughly cleaned; and after the film has been formed, a part of the "fly" may be shaken off or otherwise got rid of in the subsequent processes, but the greater part is fixed in the finished yarn and the result is most prejudicial. In dyeing delicate shades and light tints some parts of the yarn will take up more of the coloring matter than other parts, and give an uneven and blotchy appearance to the piece. The reason of the extra dye being absorbed is, of course, the fact that the "fly" acts similarly to a sponge.

In every class of cotton there is an amount of short fibre which ought to be removed, under penalty of lowering the quality of the yarn; and if this be not done the quality of the yarn

must inevitably suffer. There is no reason or excuse for making unnecessary waste, but it is better to err (if error there must be) on this side rather than the other. In the very lowest classes of yarn this is not so important, the main qualities sought being weight and filling. The amount of waste which should be taken out will vary, and no absolute rule can be given. But this much is certain, — the wire should have the ability to retain the dirt and fly, once placed in the spaces between the teeth; and the wire, when filled, should be stripped without delay. The time a card can run with a given production, under this condition, may be readily ascertained; and when this time has expired, if the card be not cleaned the inevitable result is dirty and irregular yarn. A difficulty of side-ground wire is the stripping of the flats, and when a card has been started it has often been found necessary to put a metallic brush, instead of the ordinary bristle hair-brush, to smooth the teeth of the flats sufficiently to allow them to strip. When this brush has worked a certain length of time the flats will strip almost as easily as any ordinary wire, the meaning of it being that, by its constant revolution in the wire of the flats, some of the asperities caused by the side grinding in the lower part of the point have been removed. When this result has been obtained the carding is found to be irregular and dirty, and further side grinding, in places, is found to be necessary. The polishing process, it would seem, must weaken the hold of the teeth of the wire in the foundation of cloth, and according to the varying temper of the steel and compactness of the cloth, some points will be lower or higher, as they will not all spring back to the original position. This may be seen in any hardened steel cards which have been worked a year or two. Besides, this polishing is an extra work which ought not to require to be done when a card is clothed and ready for work, and, if necessary, should be completed before delivery by the maker. It may be said that it is an axiom that the less you have to strain or distress the wire, once on the card, the better; and as the ultimate strength of the card clothing is the cloth

foundation, the less it is interfered with the longer it will last. The reason that the carding becomes dirty as soon as the side-ground wire is polished, is that, the asperities being removed, the taper interstices of the wire have less power to retain the dirt and "fly," which, consequently, go with the good cotton; and the reason of the irregularity is that a large percentage of the power of holding the long cotton has also been removed, and the fibres are taken more in tufts or bunches.

The undercasing extending from the point of contact of the doffer and cylinder is of importance when it is desirable to limit the amount of waste or to prevent unnecessary waste. It will be conceded that the work of the doffer in receiving the cotton from the cylinder is not absolutely perfect, and a proportion of long fibres, which varies from 1 per cent. to 2½ per cent., is not laid upon the doffer in each revolution of the cylinder. Then, if there were nothing immediately below the wire of the cylinder, these fibres by gravity and centrifugal force would part from the cylinder wire and become waste. The undercasing, which should be most accurately constructed, is capable of being regulated within a short distance of the cylinder wire, is perfectly smooth on its inside surface and is provided with alternated triangular bars and spaces, the angles of which are arranged with due regard to the centrifugal and tangential action in such a way that the long fibres of good cotton are retained and the loose part of the fly and dirt rejected. The long fibres being also loosened, to an extent, from the teeth of the cylinder, are in a condition to conjoin the cotton delivered by the licker-in and be transferred to the doffer in the next following revolution of the cylinder.

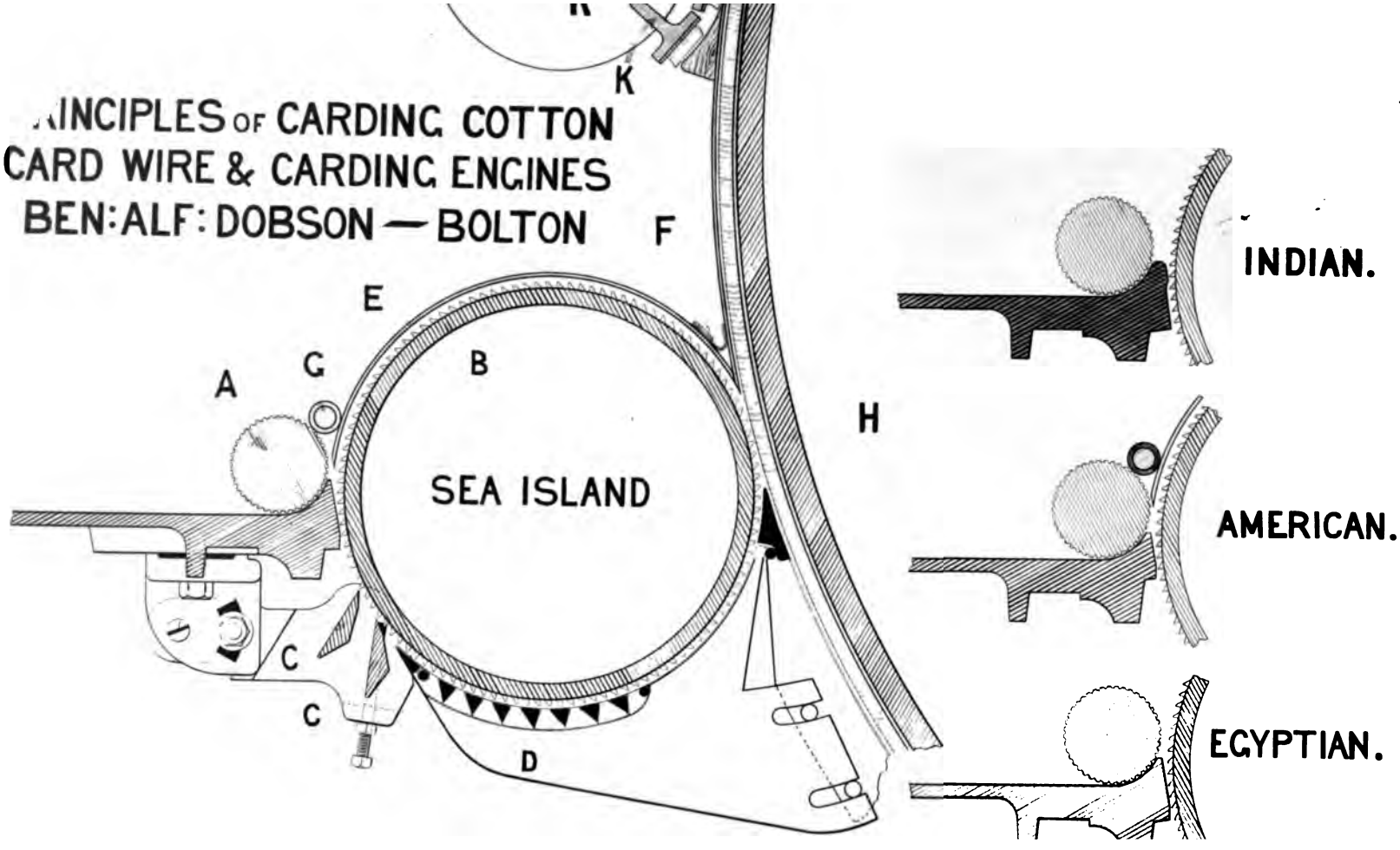
It has been observed by chemical and microscopical examination that the outside cover of the cotton fibre is a very delicate wax. If at any time in the working of cotton, deposits of very fine or impalpable white powder can be observed, it is absolutely certain that the waxy covering of the cotton fibre is being excoriated to the great detriment of the "lustre" and of the strength and elasticity of the yarn. On one occasion I

found, out of 140 cards in one card room, clothed by most of the best makers in the country, 9 cards which showed on the coiler top, opposite the sliver hole of each card, a little heap of this impalpable white powder, and upon examination I found the wire to be hardened and tempered needle-pointed. My opinion then, which has since been confirmed, was that the cotton fibres being further down than the points of the wire, had to be drawn across the extremely fine serrations caused by the needle-pointing or side grinding and thus scraping or excoriating the outside cover of the fibre. This has been proved by the fact that constant stripping with a wire brush has smoothed the wire sufficiently to prevent the recurrence. In any card a degree of this defect may be found out, but as a rule it is infinitesimal. The only time I ever saw this so marked as in the case stated was on the coiler of some dozen Heilmann combers which had been started without the nippers being covered with leather. I have also found out by some microscopical examinations made for me by the curator of the Bolton Museum, Mr. Midgeley, that excoriation of the outside cover of the fibre reduces the natural twist of the cotton, and to a small extent the strength, but reduces to a great degree the elasticity of both fibre and yarn. I have lately seen the report of very careful trials made in Alsace of various classes of wire, and I may say that both experiences tally fairly well. The Alsacian report is, however, even stronger in expression against needle-pointed wire. I hope I have made it quite clear that all my adverse criticism is not to the hardened and tempered steel but to the result of the side grinding. My principal objection to hardened and tempered steel is that the wire is never so smooth as iron wire and is generally much rougher, due to the scurf left on the surface in the process of case hardening. If the wire can be sufficiently polished and the mill hands will apply sufficient intelligence and patience in the grinding, there is no reason why hardened and tempered wire should not do thoroughly good work without damage to the cotton, while at the same time presenting the advantage of economy of time in

grinding. Whether hardened and tempered wire should or should not have a layer of natural india-rubber is at present an open question. Most makers recommend it, as they say it holds the wire in its original place and by allowing a springy or elastic motion while grinding prevents the snapping off of the steel points. On this point I prefer not to give any opinion at present, further than stating that the question of the use of natural india-rubber is very much dependent upon the climatic influences. I am informed that in the climate of this part of America, with the extreme gradations of heat and cold, the india-rubber quickly loses its properties and disintegrates, thereby utterly spoiling the clothing. In any case the aim of the card wire maker should be to proportion the foundation to the wire, and, in the case of hardened or tempered steel wire, the cloth foundation should be as firm, close, and compact as the possibilities of manufacture permit. In carding, the nearer perfection in construction that can be arrived at the better the process will be done, and nearly all makers of cotton machinery for a number of years past have been forced by the exigencies of the trade to considerably amend and improve their former methods of construction. All the framing of the machine has been considerably strengthened and more firmly tied together. The diameter of the cylinder shaft and the length of the bearings have also been considerably increased; the cards have been closed up by concentric casings where in former days spaces were left which allowed accumulation of "fly" and "dirt." Endeavors have been made to regulate the setting of the working parts to a degree of fineness that in former days was unknown and would have been impossible. I will proceed to give as briefly as possible a description of the "Simplex" carding engine, which has proved such a success in England and on the continent, and it will be understood that in doing this I do not make any invidious comparison between this card and any other.

On diagram No. 1 will be seen the feed part of the card containing the dish feed roller *a*, licker-in *b*, under-knives *c*,

[illegible]
[illegible]

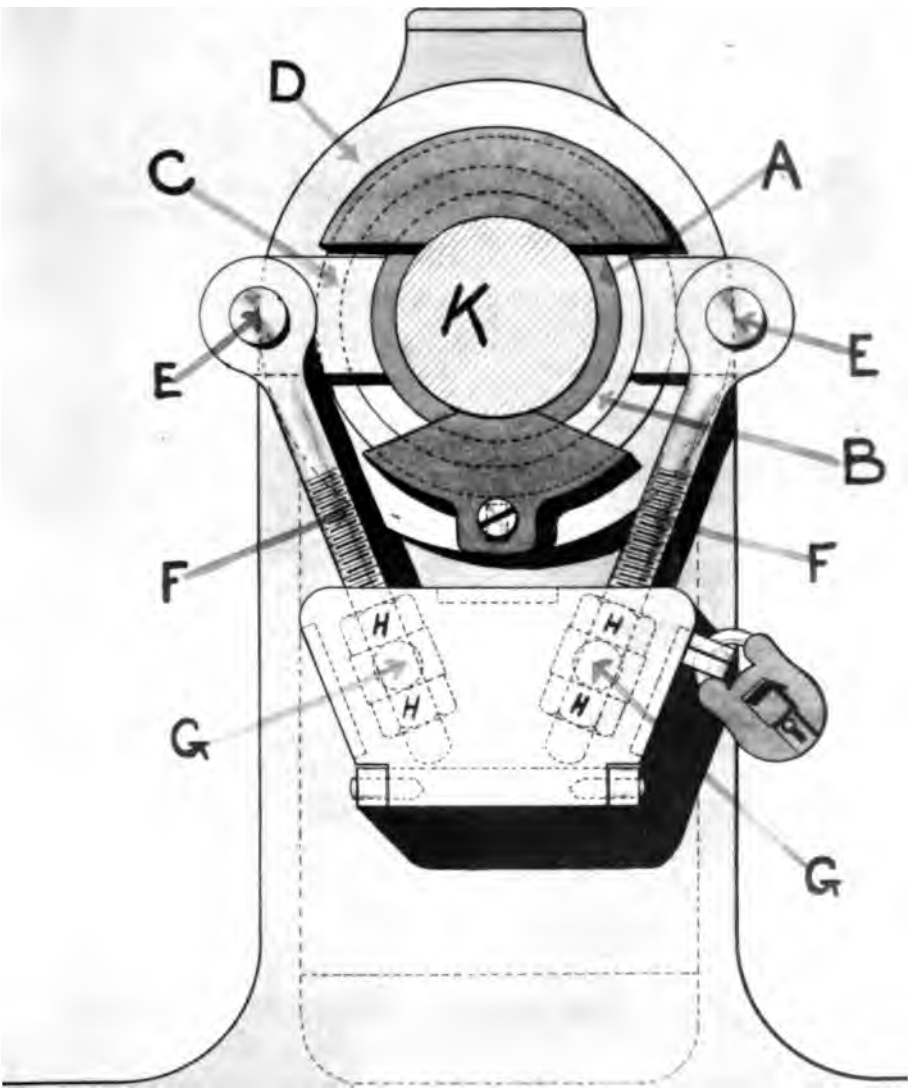

PRINCIPLES OF CARDING COTTON
CARD WIRE & CARDING ENGINES
BEN: ALF: DOBSON — BOLTON
K
F
E
B
G
A
H
SEA ISLAND
C
C
D
INDIAN.
AMERICAN.
EGYPTIAN.

and undercasing *d*, together with the concentric casings *e* and *f*, in steel plate, planed and polished inside and out, with the feed roller clearer *g*, to prevent blowing out or draughts, and a portion of the cylinder *h* and flats *k*. The diagram shows the various arrangements for Indian, American, Egyptian and Sea Island cottons, and also shows the degree of fineness of the points of the inside casings and also the exactness that they can be regulated to. The knives can be altered in position and angle without any difficulty, to suit the various lengths of staple. The object of the variation in the front part of the feed plate is, of course, to enable the points of the licker-in wire to comb out gradually the staple without at any time being able to seize the fibres, which are firmly held by the feed roller and lap. (See diagram No. 26.) The undercasing is made as exactly as any other portion of the card, and is of the very greatest importance. Proceeding to the cylinder, diagram No. 2, the cylinder shaft journals *a* are 2½ inches diameter, made of the hardest cast-iron; they turn in phosphor bronze bushes *b*, placed in the pedestal which is cast in one piece with the bend, and have a length of rather over 5 inches, or more than twice the diameter. In the original patent there was an arrangement for setting by the cylinder through wear of the shaft or bushes. We have made these special bronze bushes which have now been running for over nine years. We have taken out these bushes for examination and found that in both the cylinder journal and the phosphor bronze bush the original polishing marks were still discernible; therefore, if after nine years' working there was so little wear that it was not measurable, it seems to us useless to add to the complication of matters and cost of the card, and introduce another point where error might be possible. I may here say that with our system of setting the flats, as I will explain immediately, no cylinder adjustment is necessary to counteract any difficulty or defect in the setting of the flats. We prefer the cylinder journal to remain in its exact position as long as the card will run, and we fancy that one reason of this adjustment being

adopted by other makers is the difficulty that they have found in their systems for adjusting the flats to the cylinder. In any case, I will make myself responsible for the statement that with properly constructed journals and efficient oiling, and any reasonable tightness or length of strap, there will be no such wear as will occasion the spinner any anxiety, or any loss of quality of his carding, for a period of ten years. When I say ten years I do not mean to limit myself to this period, but our experience in this description of bearing only dates for the ten years; but should there be the two-hundredth part of an inch wear, the spinner by simply removing the pulleys on the ends of the driving shaft of the cylinder and taking out a screw *c* from each phosphor bronze bush, can with a key turn the phosphor bronze bush half round, which will mean placing the cylinder in its exact original position, and providing for another ten years' wear. As regards, therefore, the wear, we have not as yet found any that have ever worn sufficiently to require consideration, but after, say twenty years' working, it would mean, perhaps, replacing the phosphor bronze bush by one of slightly smaller inside diameter. This is a simple process and one that is very easy. As, however, much has been said lately as to the need of some method of regulating the position of the centre of the cylinder shaft concentrically with the flats, both on account of the downward wear of the bearings and also of the side pull caused by the driving strap, I will show very plainly that this matter has by no means escaped attention.

In diagram No. 8 you will see the method by which absolute mathematical accuracy may be obtained. The phosphor bronze bearing *a*, usually supplied, is placed in an eccentric *b* which, in its turn, reposes in an eccentric *c*. Both these eccentrics and the bush are contained in the cylindrical hole in the bend pedestal. This hole is the centre from which all turning and adjusting is executed. On the pedestal is a rim or boss *d*, turned most accurately at the same time as the rest of the bend framing. The bush is set originally in the centre of the pedes-

RINCIPLES OF CARDING COT
RD WIRE & CARDING ENGI
EN: ALF: DOBSON — BOLT



tal hole. Both the eccentrics have an ear, in which is fixed a stud *ee;* links *ff* connect these studs with other eye-bolts *gg*, swivelling in the lower part of the pedestal, and supplied with lock nuts *hh*, fitted on a screwed part of the links. Now, it will be evident that if the eccentrics (which have each the same throw) are moved round by turning the nuts, the centre of the interior bush will be displaced by moving round the centre of the eccentric that has been turned. If both eccentrics are turned through the same angular space, the motion of the interior bush and cylinder centre will be a straight line up or down. If one eccentric be moved more than the other the cylinder centre will be displaced laterally, and thus allow any adjustment for side wear. The interior bush is flanged, and has at one part a slot; and a stud screwed into the pedestal, through this slot, prevents any lengthway or circular displacements. The eccentrics are kept in place by the shoulder on the cylinder shaft and the flange of the interior bush. All these parts are made to template gauges, and have no play allowed, and when once regulated are fastened and fixed rigidly by the lock nuts being tightened. As the proceeding of regulating the cylinder bearing occurs so very rarely there is no wear and tear, and the screws, nuts and bushes should last as long as the mill foundations. The bush can, of course, be replaced in a few minutes when requisite.

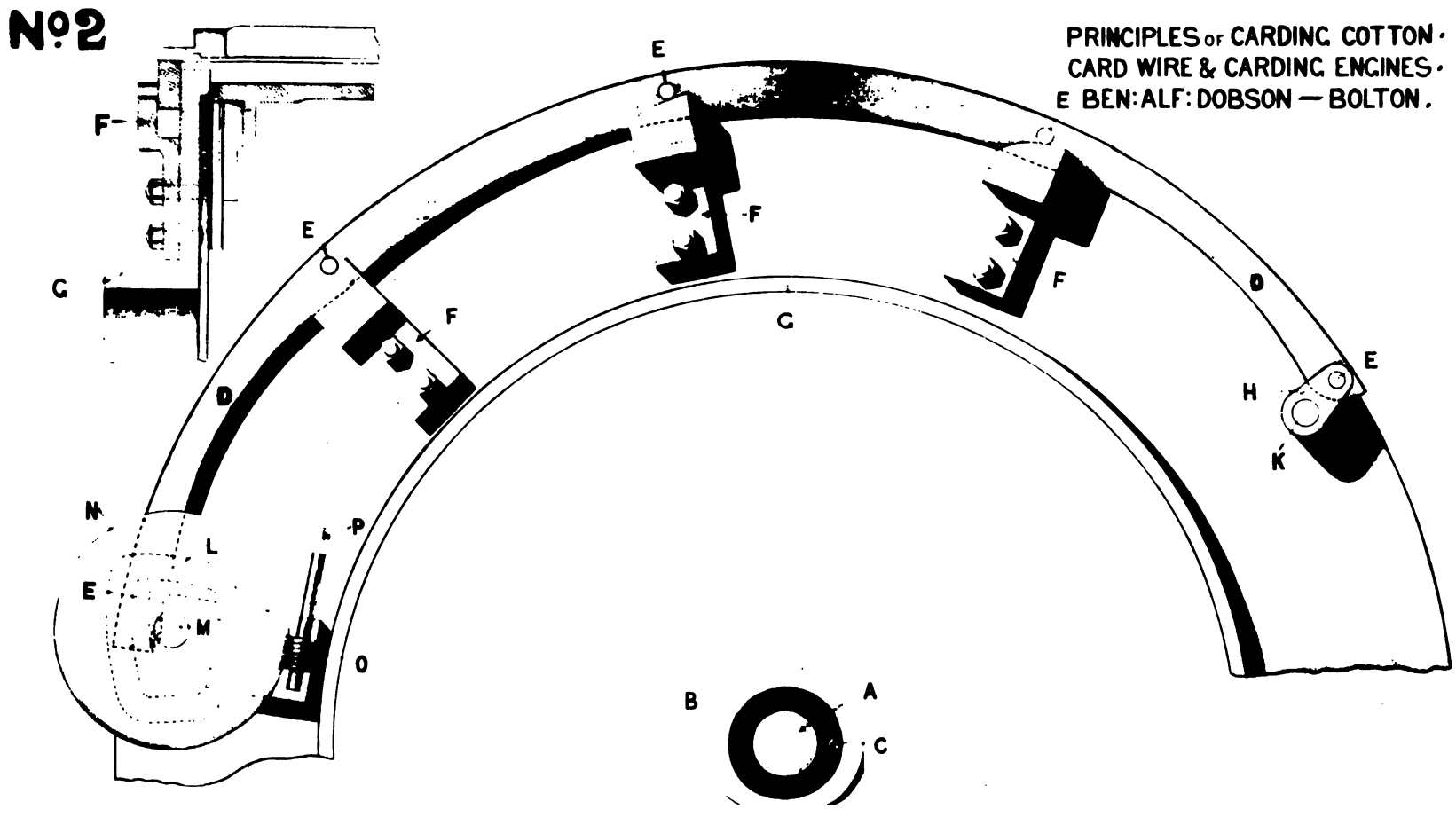
For the original regulation of the cylinder centre we have a tester gauge *l*, which fits exactly on the cylinder shaft *k*, and is turned out to fit the boss *d*. All this is done to Whitworth's gauges. This tester is passed on to the shaft, and if it will also pass on to the boss the cylinder centre is concentric with the turned bend. Should the tester not pass on freely the nuts will require turning, and the spaces in the flange of the tester will show how much and where this must be done. The whole adjustment is covered by a hinged box, fastened with a lock, and the same key as the flexible adjustments. For the purpose of regulation in the mill, when the card has been working, we provide a tester which can be placed on the shaft between

the boss *d* and the pulleys; and as it fits only half round the shaft it can be placed in position without the need of removing the pulleys. With ordinary care this tester is as good as the first-named, and a regulation to the one one-thousandth of an inch is not only practicable but easy. I may here say that my firm does not attempt to regulate the flexible bend until the cylinder has run in its bearings at 200 revolutions per minute for two days, which allows the shaft to bed definitely.

Of course as the adjustment made does not vary in any way the position of the cylinder bearing, relatively to the cause of wear, the adjustment remains correct. I believe that this is the only method of regulating the position of the cylinder centre permitting upward, downward and lateral adjustment with an absolutely certain test of accuracy. It adds somewhat to the cost of the machine, and is only applied when requested. It allows of a displacement of the centre $\frac{1}{16}$ of an inch vertically and $\frac{1}{32}$ of an inch laterally. It can be applied to all cards constructed on the "Simplex" principle. Given the cylinder permanently in centre, we now come to the method of setting the flats, which is one of the principal patents in the "Simplex" carding engine.

The setting of the flats is done in the following manner:—

The flexible bend *d*, which has been very considerably strengthened, is supported on five points by steel case-hardened pins *e*, is held between brackets *f* turned on the inside, and the turned face of the bend *g*, so that the flexible bend is held between two turned surfaces, and there can be no vibration laterally. The portion of the flexible immediately over the doffer is held by a short link *h*, which is free to swivel on its centre *k*, and the three intermediate setting points are brackets *d*, having on them a curve which theoretically and actually represents the travel of a point upon the flexible bend, traced by its motion longitudinally and radically. Diagram No. 3 shows the principle upon which the curves are worked out. The three concentric red lines show the extreme of travel of the flexible bend, presuming that, instead of simply setting


No2
PRINCIPLES OF CARDING COTTON.
CARD WIRE & CARDING ENGINES.
E BEN: ALF: DOBSON — BOLTON.
F
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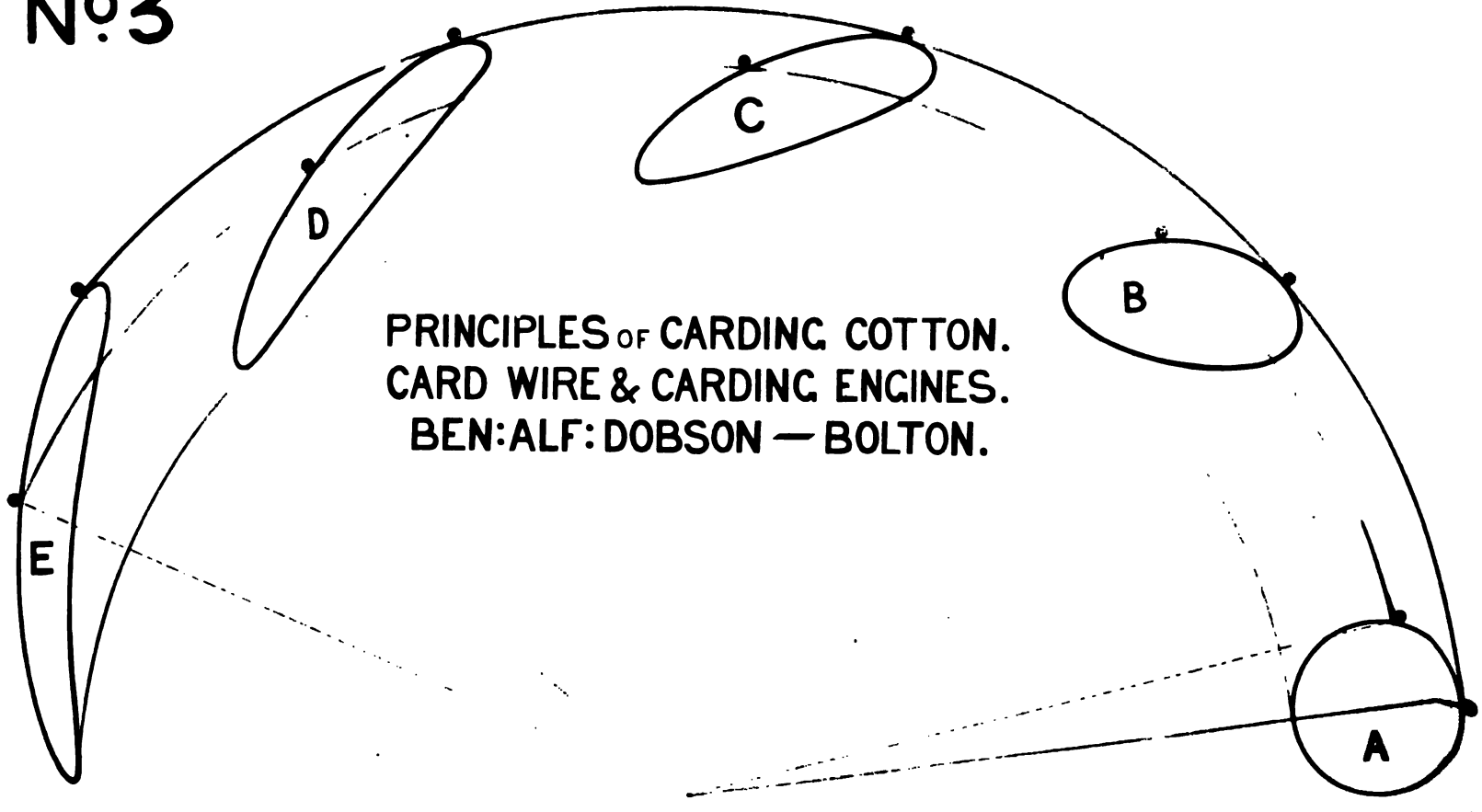
No. 3



PRINCIPLES OF CARDING COTTON.
CARD WIRE & CARDING ENGINES.
BEN: ALF: DOBSON — BOLTON.

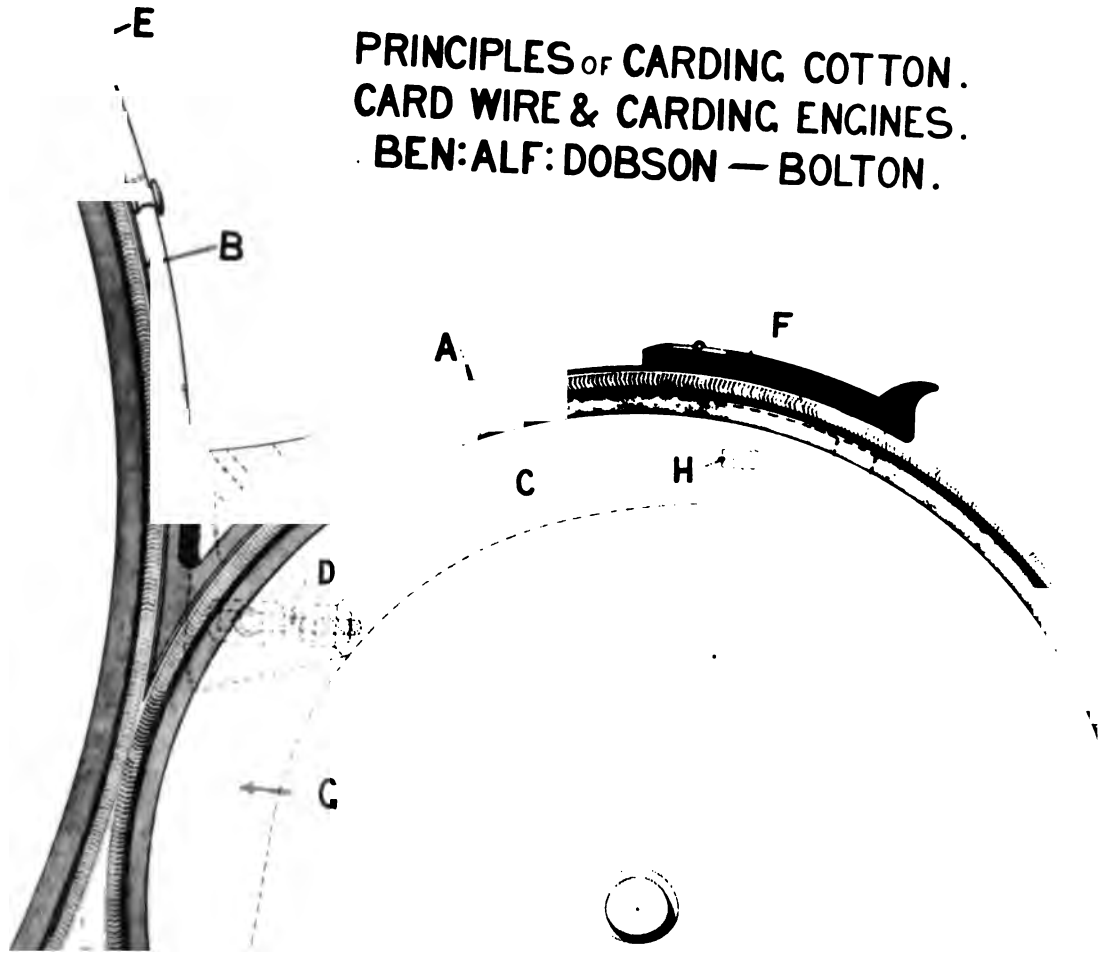
down the distance required for the concentricity of the flats, the small lever *h* worked to the development of a full circle. The circle on the right hand *a*, and the various deformations of this circle in *b*, *c*, *d* and *e*, show the travel of the five setting points, starting with the lever *h*, set radially to the centre of the cylinder. These curves are cut by a milling machine with a copying apparatus, the copy being three times the size of the finished work, thereby reducing the elements of error. At the side over the licker-in are the real setting points. There is a finely cut rack *l* in phosphor bronze inserted into the end of the flexible, into which works a steel wheel *m*, on the end of which is a wheel *n* of 160 teeth, fine pitch; a worm *o* working into this has on the end of its shaft a square *p* for a key. The index wheel *n* is marked with engraved explanations showing the amount of setting that has taken place. The dial is marked in fiftieths of an inch, and each fiftieth of an inch will represent somewhere about the two-thousandth part of an inch downward movement of the flats. The end of the shaft is fastened by a lock and key, and as it is at the end of the card immediately over the licker-in, there would in no case be any difficulty in obtaining sufficient access to set. The setting apparatus is on either side of the card. This apparatus has proved thoroughly reliable, and both practically and theoretically correct; in no case has a variation of more than a five-hundredth part of an inch been found to exist, and this has of course been corrected. It will be seen on referring to the diagram in the left corner of No. 2 that the flange of the cylinder works very close to the turned flange of the bend, and that between the edge of the wire and the flexible itself there is only the thickness of the bend. This enables us to clothe the cylinder and doffer right up to the edge of the flanges, and permits of our carding a lap somewhat wider than the card itself. We prefer laps one-half inch wider than the width of the cylinder, and we can guarantee absolutely perfect selvages on both sides of the card without any blowing or dropping of loose fibre. It will be observed that there are

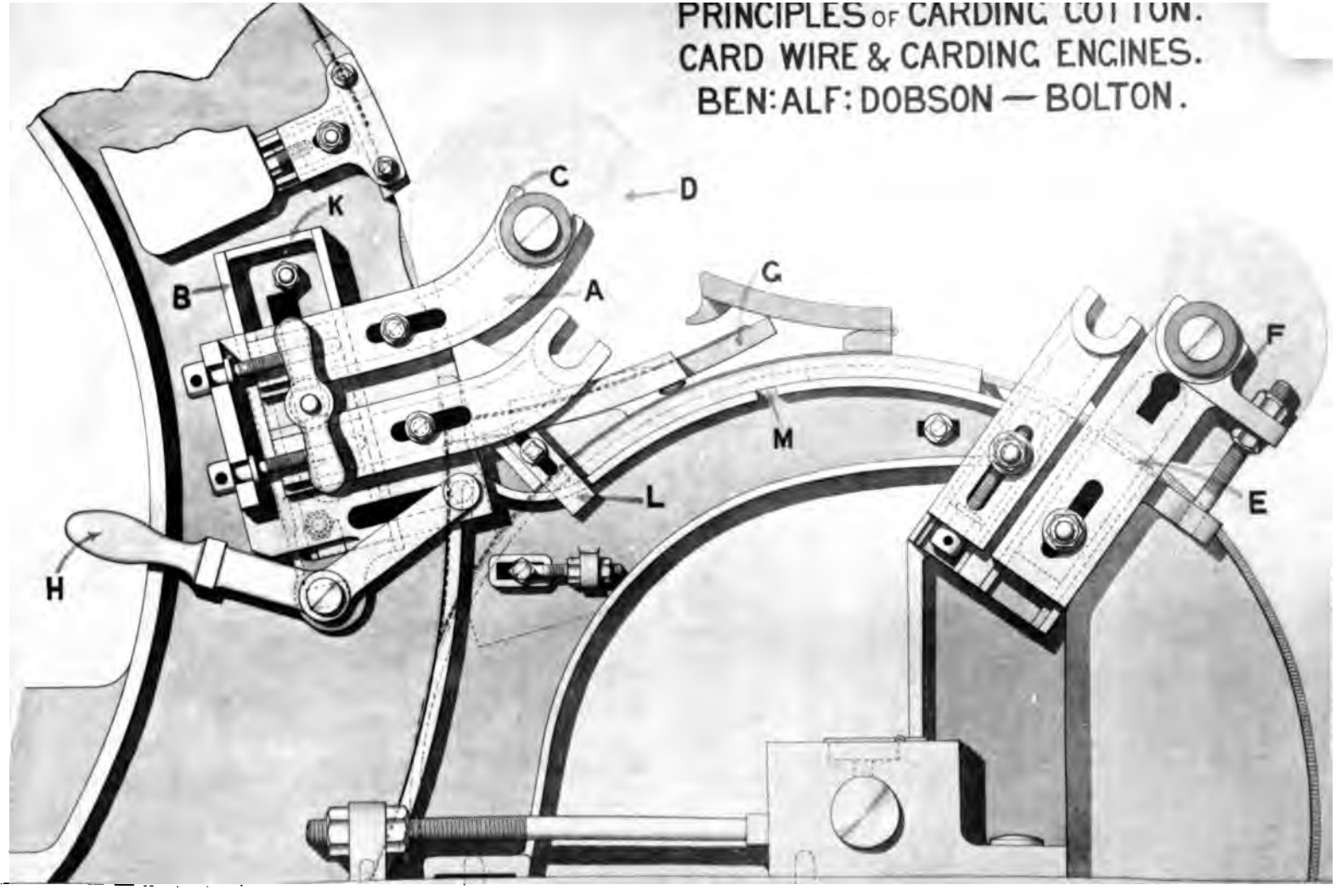
no flanged discs on either cylinder or doffer to interfere with the grinding, nor is there anything exceptional or abnormal in our system of grinding.

Now, I will at once proceed to say that the only importance to be attached to this method of setting is the fact that absolute accuracy can be obtained, that it is simpler, and only one setting at each side is required, and that it will be quite practicable for a manager of a large mill to set the whole of his cards in a very short space of time, and having possession of the key himself would know that by no means could meddling workmen alter the setting. Some considerable time ago my firm took out a patent for an improved cover between doffer and cylinder, *and* this improvement was forced upon them by the continual complaints of cotton spinners that cotton fly would collect in the interstices of the cover or covers, and that when of a sufficient volume would be caught by the cylinder or doffer and come out in the "web" or "fleece" in the front, from time to time, in the shape of thick, cloudy places. This defect in the card has been absolutely cured once for all by the adoption of this patent cover. In diagram No. 4 this patent cover is very clearly shown. This cover is of steel in three parts,— one *a*, the portion that descends between the doffer and the cylinder, is planed and polished so as to afford no chance of cotton catching and forming "cat tails." It is hollow in the inside, to form a box to allow the strippings from the flats to fall into it. There is a steel cover *b* hinged to this box in such a manner that there is no joint visible or perceptible next to the cylinder on the inside, and it has also a cover *f* hinged to it in the front to cover it to the centre of the doffer. This whole cover is carried upon two plates *c*, which are turned and which are carried in their turn on the noses *g* of the bend. These noses are turned also to the radius of the outside cylinder bends, and are provided with horizontal slots *h* and drag screws *d*, so that the whole cover can be set to the greatest nicety to the wire of the cylinder and doffer. The steel cover spoken of just now shuts down upon what is known as the

No 4

PRINCIPLES OF CARDING COTTON.
CARD WIRE & CARDING ENGINES.
BEN: ALF: DOBSON — BOLTON.




PRINCIPLES OF CARDING COTTON.
CARD WIRE & CARDING ENGINES.
BEN: ALF: DOBSON — BOLTON.
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TILDEN FOUNDATIONS

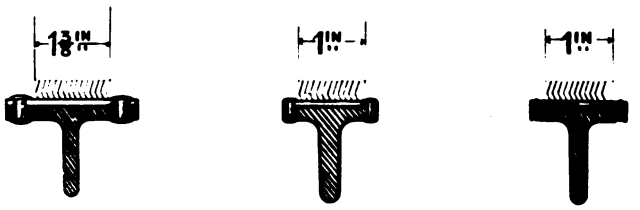
front flat knife *e*, a piece of steel fixed to a plate of cast-iron and planed to a sharp knife edge; the object of this plate, as is well known, being to avoid blowing out and to regulate the amount of waste made; the joint is closed by an inserted strip of steel.

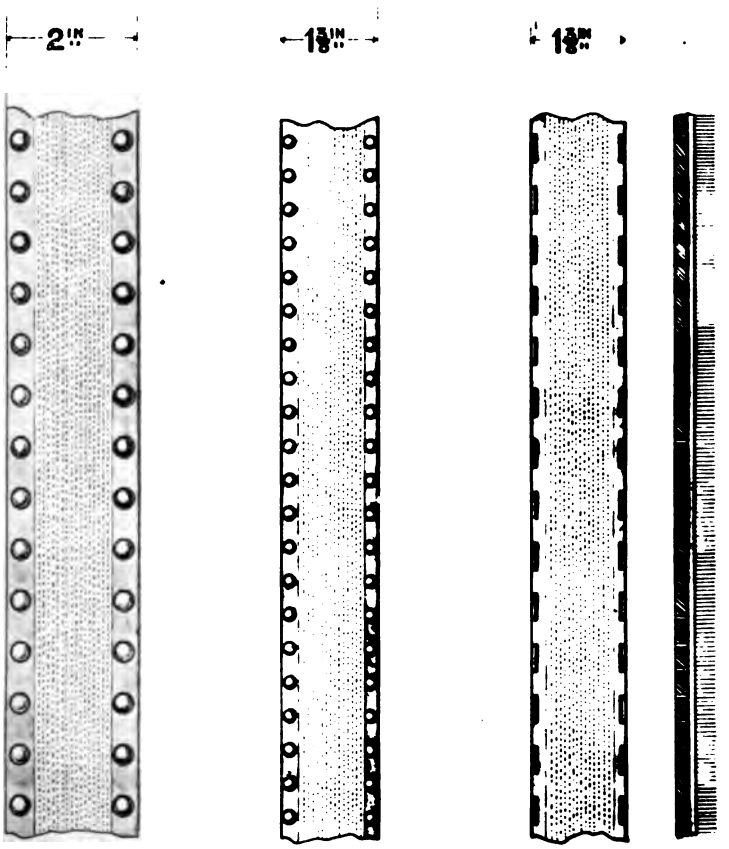
The grinding fixings are also an improvement, which allows the "Simplex" to get as many flats on a straight framing as can be got by other cards on what is termed a "set down" framing. Thus, on this card as spoken of there are 110 flats on a straight framing, neither doffer nor licker-in being set down; the consequence of this is a very important improvement in the quality of the work, owing to the extra number of flats at work, and the fact of the cylinder, doffer and licker-in being on the same level framing. For instance, in order to grind or strip this card the following would be done: The cylinder grinding fixings *a* slide in planed sides *b*, and are fixed originally to a certain height radially to the centre of the cylinder shaft, in such a way that there is no room for variation subsequently. When these slides are on their bottom bed the two bearings *c* for the grinding roller are precisely level and parallel horizontally with the cylinder shaft. When the grinding roller *d* is put in it can be set on either side, in or out, as may be necessary, but such a thing as getting the grinding roller cross-wound is absolutely impossible. This is in itself a security for better grinding, and inasmuch as this grinding takes place almost over the extreme lateral point of the circumference of the cylinder, any vibration or variation will be up or down rather than sideways, and therefore will not affect the correctness of the grinding to the same degree as if the grinding roller were higher up. The "Simplex" has also other excellent grinding arrangements. With the doffer grinding similar dispositions are taken, and the grinding fixings *e* are planed from the bearing *f* of the doffer, and being cast in one piece with it variation is impossible. In grinding the cylinder it is only necessary to turn down the hinged portion of the front cover *b* in diagram No. 4, *g* in No. 5, then the

framing allows the grinding roller to traverse over, and after grinding, to brush out; it is only necessary to lift the slide blocks on either side of the card by a handle *h*, provided for this purpose, up to the top stop, and then the supports are in their exact position, and the stripping-out brush can be set in or out. This permits us the use of any diameter of stripping brush or grinding roller independent one of the other, and also the use of either wire or bristled brush as may be considered desirable, and as will be seen this apparatus only requires the room generally taken up by one fixing. The opening caused by the turning down in this cover is also sufficient for stripping purposes, and when it is requisite to set the doffer to the cylinder all that is necessary is to swing the cover back upon its two supporting plates until the catch *l* on each side drops into a groove *m*, and then the cover is safely retained while setting proceeds. When the doffer is thoroughly set all that is necessary is to lift the catches on either hand and allow the plate to slide quietly down to its bearings; this can be done by one man. One effect of this particular arrangement of covers has been that draughts in the inside of the card have been avoided to such an extent that it is now possible to card a lap the full width of the cylinder wire. It will be noticed that there is no wood employed in the construction of the interior of this card whatever, the linings, or sweeps as they are called, surrounding the cylinder are parts of the bends, and turned in the lathe at the same time, — in fact, the whole interior of the card is planed or polished. What I contend is the advantage of a card constructed on the principles such as I have described, is, that it is not dependent upon any particular class of wire, and can be set as practically and as advantageously for the ordinary iron wire as for hardened and tempered and needle-pointed.

This card is made with 110 flats, of which 44 are constantly at work. The width of wire is 1 inch of net wire (see diagram No. 7, which shows the old system of rivets and the wide flat 2 inches, the new system of rivets with 1 width of flats and the

PRINCIPLES OF CARDING COTTON.
CARD WIRE & CARDING ENGINES.
BEN: ALF: DOBSON — BOLTON.





RIVETS. RIVETS. WIRE SEWN.

"wire-sewn" flat also with 1 inch width of wire). It is possible in both the cases of the rivet and the sewn wire to get a little more width than this 1 inch, but we do not consider it advisable, as it pinches the room for doing the work of riveting with sufficient care of either the rivets or fixing the sewn wire, and we are also of opinion that it is advisable to have a certain space between the wire and one flat and another. The fact is, that we have not found it desirable to reduce the space between the flats any more than has been done in the examples shown. I maintain that the flat with the rivets is stronger and less liable to deflection than the wire-sewn flat, for this reason: that the exterior edges of the flat with the rivets are left intact, whereas in the wire-sewn flat they are nicked at each end of the wire staples. This nicking or cutting of the edge weakens the resisting power of the flat in both directions, laterally and vertically, very considerably. Of course it is well known that the strongest portion of a casting is that adjoining the outside skin in the casting. As a practical result the wire when put on by the rivets is more exactly in the centre of the flat and is held more firmly and more evenly stretched than it is with the wire-sewn flats.

This table will show the different deflections of the several sizes of flats, indicated when in a vertical position ⊥ for carding, on their side ⊢, or when face upwards T for grinding, with and without clothing, and whether clothed with rivets or wire-sewn: —

Width.	Length.	Clothed.	How Clothed.	Unclothed.	Deflections.						Thickness of Flat.	Thickness of Web.
					T When Grinding.		⊢ Side.		⊥ When Carding.			
Inch.					1 Lb.	2 Lbs.	1 Lb.	2 Lbs.	1 Lb.	2 Lbs.		
2	45⅝	–	–	Yes.	1–1140	1–660	1–1000	1–620	1–800	1–420	.196	.206
2	45⅝	Yes.	Rivets.	– – –	1–1140	1–660	1–1350	1–720	1–880	1–500	.196	.206
1⅝	45⅝	–	–	Yes.	1–1000	1–660	1–880	1–570	1–14[illegible]0	1–700	.189	.283
1⅝	45⅝	–	–	– – –	–	–	–	–	–	–	–	–
1⅜	45	–	–	Yes.	1–880	1–500	1–700	1–480	1–1000	1–500	.200	.275
1⅜	45	Yes.	Rivets.	– – –	1–900	1–500	1–1330	1–660	1–1330	1–660	.200	.275
1⅜	42	–	–	Yes.	1–1330	1–660	1–800	1–450	1–1330	1–660	.200	.275
1⅜	42	Yes.	Rivets.	– – –	1–1600	1–880	1–720	1–400	1–1330	1–650	.200	.275
1⅜	45⅝	–	–	For sewing, yes.	1–380	1–200	1–330	1–166	1–660	1–400	.196	.225
1⅜	45⅝	Yes.	Sewn.	– – –	1–720	1–440	–	–	–	–	.196	.225
1⅜	45⅝	–	Rivets.	Yes.	1–1000	1–500	1–460	1–275	1–875	1–460	.192	.225

Nº 6

PRINCIPLES OF CARDING COTTON.
CARD WIRE & CARDING ENGINES.
BEN: ALF: DOBSON — BOLTON.

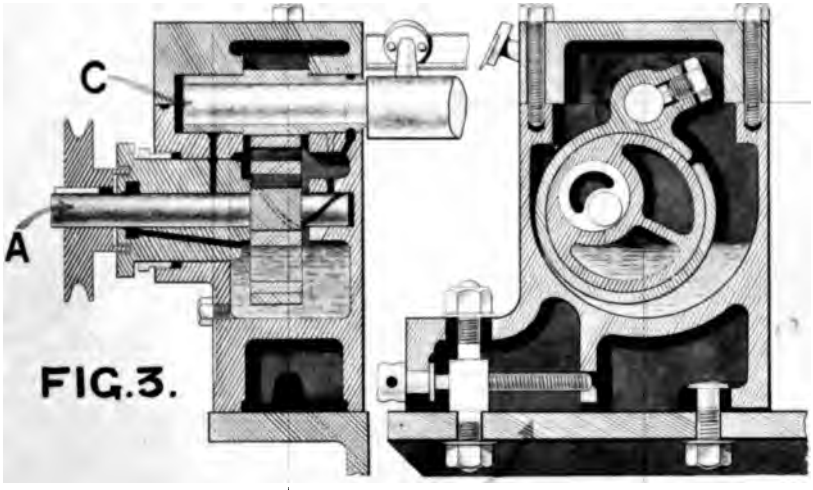


FIG. 3.

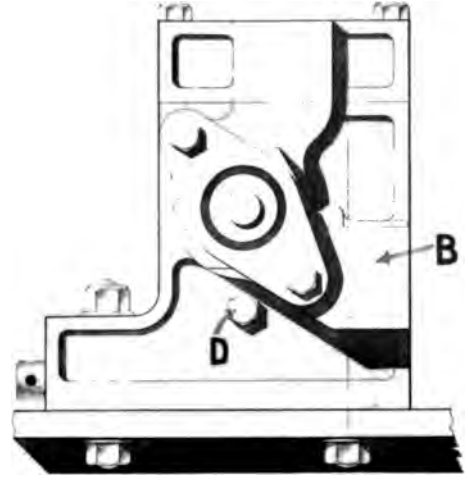


FIG. 1.

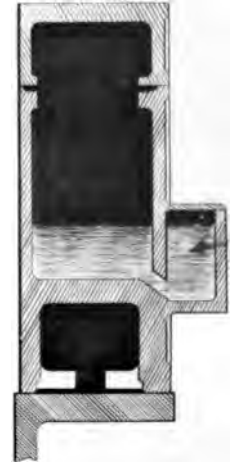


FIG. 3A

FIG. 2.

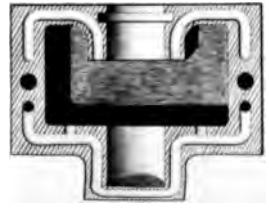


FIG. 4.

COMB BOX

With regard to the patent doffing comb motion: Referring to the illustrations, Fig. 1 is an elevation, Fig. 2 a sectional elevation, Figs. 3 and 3*a* other sectional elevations at right angles to Fig. 2 and Fig. 4, a plan with the lid removed. The apparatus is driven by a band on the pulley on the spindle marked *a*. As in Figs. 2 and 3 there is turned solid with this spindle a small eccentric which is enclosed in another eccentric, or rather this large eccentric is the strap of the smaller one. The shaft *c* is the comb shaft which it is required to vibrate; it is fastened to it by the set screw of the larger eccentric. The centres of the spindle *a* and the comb shaft *c* are of course stationary, and as the spindle *a* revolves continuously, the eccentric that revolves with it must vibrate the large strap and therefore the comb shaft. The larger eccentric does not revolve in its strap, but simply works backwards and forwards through a small arc. A very great advantage attached to this motion is, as will be seen, that the work in manufacturing it can all be done with the lathe and milling machine, there being no hand-fitting required, and therefore interchangeability is very easily obtained. The lubrication of these motions, in view of the great speed at which they run, and the severity of the work they have to perform, is a very important point, and much attention has been given to it in the motion illustrated. The eccentric work submerged in oil is shown in Figs. 2 and 3, and with the rapid oscillation of the strap or lever *c* the oil is projected all over the internal cavity of the motion, loss being avoided by a cap which is screwed on the top. The oil then enters the dark groove shown in the plan Fig. 4, and which is on a level with the centre line of the comb shaft, which it thoroughly lubricates, and then falls into the reservoir below. Much the same mode is provided for the oiling of the eccentric spindle *a*; none of the oil can escape along the spindle, it being trapped by the groove shown in the bush. The escape of oil round the bush itself is prevented by a ring of asbestos kept in its place by a screwed gland. The oil is admitted by the box *b*, which is covered with a lid, and

as long as the oil does not overflow this box it will be the right level for working and lubricating the eccentrics. For the purpose of cleaning this box there is a tap screw *d*, which can be unscrewed for the purpose of letting out the dirty oil from the lowest level. A great merit of this appliance will be at once recognized by those present. It has no parts projecting from the inside or from the doffer side of the motion. It is therefore much easier to keep clean than those motions in which it is necessary to have projections. Fly and dirt tend to accumulate in the recesses between them, and sometimes enter with the web, which, of course, is not a desirable contingency. The Simplex card, as compared with ordinary cards, will easily produce ten per cent. more work than any ordinary card, on account of the possibility of working the whole width of wire, that is to say, 41 as against 38 inches. On the other hand there is a clear ten per cent. in quality of carding gained by the extra number of flats, as there are 44 flats always fully at work.

A complete geometrical drawing of this card is also shown, from which any details that I have not mentioned can be seen, but as many of the other details are of course common to all carding engines I do not consider it necessary to take up your time by a description of them.

I now give you the results of a microscopic examination of 25 samples of card clothing, together with diagrams representing side and front views of the teeth, and longitudinal and transverse sections of foundations enlarged 64 diameters (No. 25 enlarged 32 diameters) and point of each about 420 diameters. Plan of points of teeth in samples 9*a*, 21*a*, and 23*a*, enlarged 96 diameters.

1. Hardened and tempered steel round wire; sides ground flat, from $\frac{3}{4}$ of an inch to the bend. The surfaces of the ground sides are covered with deep striæ, and on the front margin the grinding has left irregular sized lumps of steel hanging over, giving the front a serrated aspect. Such a rough surface cannot help being injurious to the delicate waxy cell walls of

cotton fibres. Some of the points are ground so thin as to be nothing more than a film, while a few are ground off below the level. Points very slightly beaked at the front, and a few striæ on the surface of the end. Cloth composed of an upper and lower layer of cotton with a thicker layer of woollen between.

2. Hardened and tempered steel, needle-pointed, tinned, plain set. Round wire; sides slightly ground off the end to about $\frac{1}{4}$ or $\frac{1}{5}$ of an inch towards the bend, with grinding striated. The surface round the point seems as if it had been rubbed, leaving it more or less covered with small marks. The points slightly beaked, and has striæ across from back to front. Cloth composed as in No. 1.

3. Hardened and tempered steel, needle-pointed, twill set. The grinding and characteristics of wire and cloth very similar to No. 2, except that the points are ground a little flatter.

4. Hardened and tempered steel, plain set. Wire and cloth very similar to No. 2, only the side grinding shows greater striæ.

5. Hardened and tempered steel, twill set. The wire nearly a right-angled triangle, the back being slightly convex. Point beaked, surface of point striated. The points are regular in shape and evenly distributed in space; in this respect more so than in the preceding samples. Clothing as in No. 1.

6. Hardened and tempered steel, round wire, twill set, No. 130s (old sample, 6 years). The wire is blotched with erosion, particularly in the space between the bend and point. The wire seems to have been soft, and the effect of frequent grinding of the points has produced many curiously shaped bits of overhanging wire from the points, one of which is figured in the left hand of diagram. The front view also gives a good image of the way in which the grinding has drawn over the wire upon the front surface. The teeth present a decidedly longer beak at the points than any previous samples. Bits of "fly" were found attached to most of the teeth.

Cloth. A layer of rubber on the upper surface, cemented to layers of cotton beneath, the inner of which is thickest.

7. Patent wire. Round wire flatted nearly to an angle; the flattened sides are perfectly parallel, and give to the point almost an oblong square aspect. Teeth very regularly set in the plane of the flatted sides. Rubber and cotton (three-ply) equal thickness.

8. Hardened and tempered, needle-pointed. Round wire ground from $\frac{3}{8}$ to $\frac{3}{4}$ down the side, striæ very distinct; margins of the front of ground portion slightly drawn beyond the ground side and serrated. Point beaked.

9. This is a diagram of "mild steel" wire. Plain round wire, fine and bright. The point shows the usual indent made by the cutter of the setting machine. Cut at right angles. Teeth very regular and equal in interspaces. Length of teeth $\frac{19}{48}$ of an inch, from base to bend $\frac{8}{48}$ of an inch and from bend to point $\frac{47}{192}$ of an inch.

Cloth. Rubber above, rather thicker than Nos. 20, 22, 23 and 24, and three-ply cotton below, containing a greater amount of cement.

9*a*. A plan of points of No. 9, $\frac{3}{16}$ of an inch diameter, showing how regular they are set, the slight deviation from the straight line of arrangement being common to all samples.

10. Hardened and tempered steel. Plain round wire, end cut off as in No. 8, but point shows slight stria in the line of cutter.

Cloth same as in No. 8.

11. Patent rolled angular wire, hardened and tempered. Angular wire concave at the back; the front angle more obtuse than in No. 5. Very regular in form and grinding of the points. Small beak tip.

Cloth. Rubber above, layers of cotton below.

12. Hardened and tempered needle-point. Round fine wire; ground needle points with acute tapering end. Ground about $\frac{1}{4}$ of the way towards the angle.

Cloth same as No. 8.

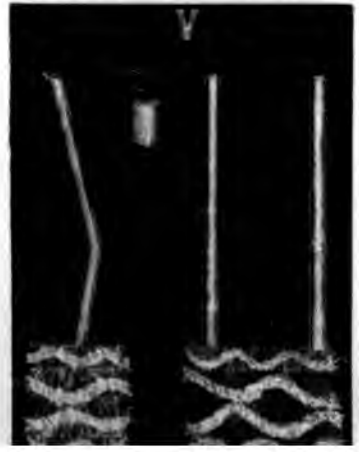
13. Hardened and tempered. Round wire, with sides as if they had been flattened $\frac{3}{4}$ of the distance to the angle by pres-

I

II

III

IV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VI

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sure in passing through the maker's machine; the flattened surface slightly furrowed.

Cloth very similar to No. 8, but more compressed and greater amount of cement.

14. Hardened and tempered plated wire. Round wire, flattened nearly to angle point, seems as if rubbed like needle-pointed, and very regularly finished. Cloth same as No. 8.

15. Tinned steel. Round plain fine wire. Ends cut at right angles. Rubber thicker than usual and not so evenly cut, the texture of cotton clothing being somewhat different.

16. Hardened and tempered, needle-pointed. Round wire, side ground, with striations on the ground surface, and front margin left with little masses drawn over upon the front of the wire. Point peaked, and regular in size and shape. Cloth same as No. 13.

17. Hardened and tempered. Plain round wire, bluer in color, points cut at right angles, with a depression on the side from which it was cut. Rubber above, very even, and cotton cloth, well cemented together. Teeth rather wide between the prongs.

18. Round mild steel No. 130s. Plain round fine wire; diameter measured 0.0077 inches, with ends cut at right angles. Proportion of length above the angle longer than usual. One of each pair of teeth is slightly bent outwards at the point. At first I thought it due to accident after the cut was made, because I had drawn specimens for examination from the side of the card. To settle the doubt I examined several teeth from the middle of the fillet, and found them to be malformed in the same way. I concluded that it had been caused by the cutter which holds the wire as it passes through the machine. Rubber and cloth (cotton) even and compact.

[illegible]. Round mild steel No. 120s. Plain round wire with ends cut at right angles; upper part of the angle long. Rubber above and layers of cotton below, the inner layer being the thickest.

20. Hardened and tempered steel surface ground. Round wire; grinding of point has not produced so much over-hanging roughness as in Nos. 23 and 24. Teeth scarcely so regularly set as in Nos. 21, 23 and 24. Length of teeth $\frac{35}{96}$ of an inch, from base to bend $\frac{17}{96}$ of an inch, and from bend to point $\frac{10}{48}$ of an inch. Width of prong $\frac{6}{48}$ of an inch. Angle of tooth from foundation 14°; from bend to point 17.5°. Cloth-rubber above, four-ply cotton below, well cemented together.

21. Hardened and tempered steel, needle-points. Round wire bright, side ground half-way down to bend, giving the point somewhat of a chisel shape. Ground surface striated, and on front side of grinding, slightly overhung with particles of steel drawn forward, but are not near so much so as in some of the previous samples of side ground. Teeth very regular in shape and arrangement. Length $\frac{37}{96}$ of an inch; from base to bend $\frac{9}{48}$ of an inch, and from bend to point $\frac{43}{192}$ of an inch. Width of prong $\frac{7}{48}$ of an inch. Teeth set in foundation at an angle of 15°, and from bend forward to point 17°. Clothing cotton above and below, with layer of woollen between, well cemented together.

21*a*. A plan of points of teeth of No. 21, as seen in the "field" of the microscope, $\frac{3}{16}$ of an inch in diameter, showing to what a thin edge the points are ground, how equal in size and regular in space.

22. Hardened and tempered steel. Round wire, surface ground even and bright; points ground nearly at right angles; ends pretty regularly set. Entire length of teeth $\frac{3}{8}$ of an inch; from base to bend $\frac{25}{144}$ of an inch; from bend to point $\frac{10}{48}$ of an inch; width of prong $\frac{13}{96}$ of an inch. Set in cloth at an angle of 15°, and from bend forward to point 16.5°. Cloth: longitudinal section of rubber on upper surface rather uneven (owing to cutter), lower side smooth. Four-ply cotton below, well compacted together.

23. Hardened and tempered steel, flat to bend. The flatted surface has very faint fine lines across the wire (not scratches such as are produced by grinding). The flattened surface

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uniformly runs to the bend. The grinding of the points has left the front and side edges slightly roughened by overhanging particles of steel. Teeth all regular in size and setting. Entire length of teeth, from base to bend $\frac{3}{8}$ of an inch; from bend to point $\frac{32}{144}$ of an inch; width of prong $\frac{19}{144}$ of an inch. Angle at which base of teeth is set in foundation 16.5°; angle from bend to point 19°. Cloth very similar to No. 22.

23*a*. A plan of $\frac{3}{16}$ of an inch as seen under a low power of the microscope. The points are very regular in shape and distributed in space, with an entire absence of serrated roughness, calculated to injure the delicate waxiness of the cell walls of the cotton fibre.

24. Hardened and tempered steel, angular surface, ground point. The wire almost a perfect triangle, with edges blunt; surface of the wire smooth and bright, points very uniform on the surface, regular spaced card and acute points all in forward direction. Entire length of teeth $\frac{3}{8}$ of an inch; from base to bend $\frac{8}{48}$ of an inch; and from bend to point $\frac{21}{96}$ of an inch; width of prong $\frac{7}{48}$ of an inch. Teeth set in cloth at an angle of 13.5° and from bend to point 21.5°. Cloth similar to No. 28.

24*a*. Plan of points of hardened and tempered angular steel wire. The points are remarkably uniformly set in space. The front angle of the wire is not true to centre, but more so than the two other samples of angular wire examined. From the fact that there are three points in the right-hand and then three points in the left-hand direction, in regular succession across the fillet, it may be the bend at the base of each pair of teeth has produced a divergence at the time of setting.

25. Stripping out fillet from main cylinder and doffer (scale 32 times). Very fine plain round wire, disproportionately long, compared with other diagrams, from the base to bend. Teeth set diagonally on the cloth, which explains the points being represented as ground in a side direction in diagram. Length of teeth $\frac{74}{96}$ of an inch; from base to bend $\frac{26}{48}$ of an inch; and from bend to point $\frac{18}{48}$ of an inch. Width of prong at the base $\frac{10}{48}$ of an inch; at bend $\frac{11}{48}$ of an inch. The

angle at which the teeth are set in the cloth is variable, from 6° to 8°, and from bend to point 15°. The points are very irregular in space and also in the grinding. The latter is shown in diagram.

Cloth composed of rubber above and two-ply of cotton beneath, the whole only about three-fourths the thickness of other rubber clothing.

These diagrams have been carefully made from specimens of card wire obtained from nearly all the principal makers, and have been observed by a microscope up to 420 diameters. Having been very carefully done I believe they may be considered to give a very fair idea of the exact condition of the wires and foundation.

The inevitable conclusion that will be drawn from a very careful inspection of these diagrams is that in all side-ground wire there is a very large amount of surface asperities, capable of injuring the delicate wax walls of the fibres, and that when these are removed, by either flattened wire or polishing the side-ground wire, a very considerable loss of carding power is sustained. The diameter of round wire is $\frac{105}{10000}$ of an inch. When ground on the card an ellipse is formed with its axis, equal to $.0105 \times .01050504$. Dimensions of side-ground wire $\frac{11}{1000} \times \frac{6}{1000}$ of an inch.

Proportions of wire to surface, per square inch: —

Round wire $\frac{1}{18}$ of a square inch is occupied by the upper surface of the wire; side ground wire $\frac{1}{25}$ of a square inch is occupied by the upper surface of the wire; half circumference of ellipse .0164973 inches.

Length of serration of wires in contact with cotton, per square inch: —

Round wire $10\frac{1}{4}$ inches; side-ground wire $3\frac{3}{4}$ inches.

This will show that, as soon as the side-ground wire has its asperities removed by polishing, the holding-power for proper carding purposes is reduced very considerably, as compared with the ordinary wire.

In the preparation of these diagrams and the whole of the

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LAP × 5

LAP X 30

microscopic examination I have been assisted by Mr. W. W. Midgeley, the curator of the Museum in Bolton, who is a very capable and enthusiastic microscopist.

Diagrams of "Lap."

Diagram 26. A diagram representing a piece of lap of cotton as it enters into contact with the carding engine. From the top to the small arrow it shows the condition in which the cotton leaves the scutcher and where the fibres are mixed in the most tangled condition. The distance from the small arrow downwards shows the front edge as it is affected by contact with the teeth of the licker-in. The fibres near the upper surface have assumed a degree of parallelism with the ends towards the engine, and as the edge thins out the fibres become as regularly parallel as can be expected of filaments so fine in a free state magnified five diameters. Arrow *a* indicates the portion of the thinned edge figure in diagram No. 27.

Diagram 27. A diagram magnified 30 diameters of the extreme margin of lap, showing how effectually the licker-in operates on the fibres as a preparatory stage to the work of the cylinder.

Reference to Diagrams of Card Wire.

Diagram Number.	KIND OF WIRE.	Width of Prong.	Total length in inches.	From Foundat'n to Bend.	From Bend to Point.	Angles in Degrees from Base to Bend.	Angles in Degrees from Bend to Point.
1	Hardened and tempered. Side ground,	7–48	3–8	10–48	9–48	7	10.5
2	H. and T. Double convex. Tinned wire. N. P.,	13–96	3–8	20–96	19–96	8.5	13
3	Hardened and tempered. Needle-pointed,	25–192	37–96	19–96	19–96	7	14
4	Hardened and tempered,	13–96	3–8	8–48	11–48	7	10
5	Hardened and tempered,	6–48	35–96	9–48	10–48	8.5	15
6	Hardened and tempered. Round,	6–48	17–48	8–48	19–96	11.5	18
7	Patent wire. Flat from bend,	7–48	20–48	9–48	47–192	6	20
8	Hardened and tempered. Needle-pointed,	6–48	71–192	21–96	35–192	8	20
9	Mild steel,	13–96	19–48	9–48	23–96	15.5	21.5
10	Hardened and tempered,	13–96	19–48	21–96	10–48	15	22.5
11	Hardened and tempered. Angular,	13–96	19–48	9–48	12–48	12.5	22
12	Hardened and tempered. Needle-pointed,	11–96	39–96	37–192	11–48	13	21
13	Hardened and tempered. Flattened wire,	8–48	19–48	17–96	23–96	12.5	20.5
14	H. and T. Patent wire. Flat to bend,	13–96	19–48	10–48	10–48	12.5	22
15	Tinned steel,	25–192	39–96	8–48	12–48	6	20.5
16	Hardened and tempered. Needle-pointed,	25–192	3–8	10–48	8–48	8	25
17	Hardened and tempered,	7–48	19–48	9–48	11–48	10	21
18	Round mild steel,	25–192	39–96	7–48	13–48	9	17.5
19	Round mild steel,	15–96	39–96	7–48	13–48	10	14
20	Hardened and tempered steel. Surface ground,	6–48	35–96	17–96	10–48	14	17.5
21	Hardened and tempered steel. Needle-pointed,	7–48	37–96	9–48	43–192	15	17
22	Hardened and tempered. Bright steel,	13–96	3–8	25–144	10–48	15	16.5
23	Hardened and tempered. Flat from bend,	19–144	3–8	25–144	32–144	16.5	19
24	Hardened and tempered. Angular. Surface ground,	7–48	3–8	8–48	21–96	13.5	21.5
25	Stripping-out fillet for main cylinder,	10–48	74–96	26–48	13–48	7.5	15

In making examinations of carding it is necessary to consider the quality of the lap presented to the card. If the cotton is already overworked, rolled and strung, or corded, and is irregular in weight and thickness from yard to yard, it is useless to expect clean and regular carding. In Lancashire this matter has received very great attention recently, and many mills have changed their comparatively new machinery for newer designs, giving certainty of cleaning and regularity. The object sought has been the very praiseworthy one of endeavoring to do the work with the least possible injury and fatigue to the cotton fibre, and to operate as seldom as possible consistent with good results. With the new class of machines it is practicable to throw the cotton from the bale on to the lattice feed of an opening machine and produce laps which will not vary from one extreme to the other more than one-half a pound up or down. The cotton should be a regular fleece with no curls, or cords, or lumps, as their presence proves that the machines are either too numerous for the class of cotton or are badly regulated. In much of what precedes I must except from the scope of my remarks Indian cotton and waste, and even those cases where American cotton is treated like Indian, — I mean where quality is entirely subject to quantity.

In speaking of carding, I have viewed, from the stand-point of practical, every-day working, the every-day problem, — how to extract the greatest value in yarn from each pound of bale cotton.

Bourcart's Patent Improved Combing Machine.

The two diagrams of combing machines show, — one the ordinary Heilmann comber and the other the same altered to Bourcart's system. The reversing motions of the piecing roller being abolished allows of an increased number of piecings per minute, and the extra comb segment and half-lap allow of the extra piecings without any extra speed of combs. I may say, briefly, that taking the very best type of Heilmann

comber producing the greatest amount practicable, the application of this improvement will increase its production 75 per cent., with an improvement in quality of combing. We have applied this on some old machines in Lancashire where double combing was previously required for Fiji cotton, and where now the new single combing suffices.

In machines not running over seventy revolutions per minute we can just double the out-turn. This is, of course, a great saving in all the items of cost of combing.

Mr. A. G. CUMNOCK. I would like to ask Mr. Dobson to tell us what kind of picking he recommends, the number of doublings and the number of beaters for his card.

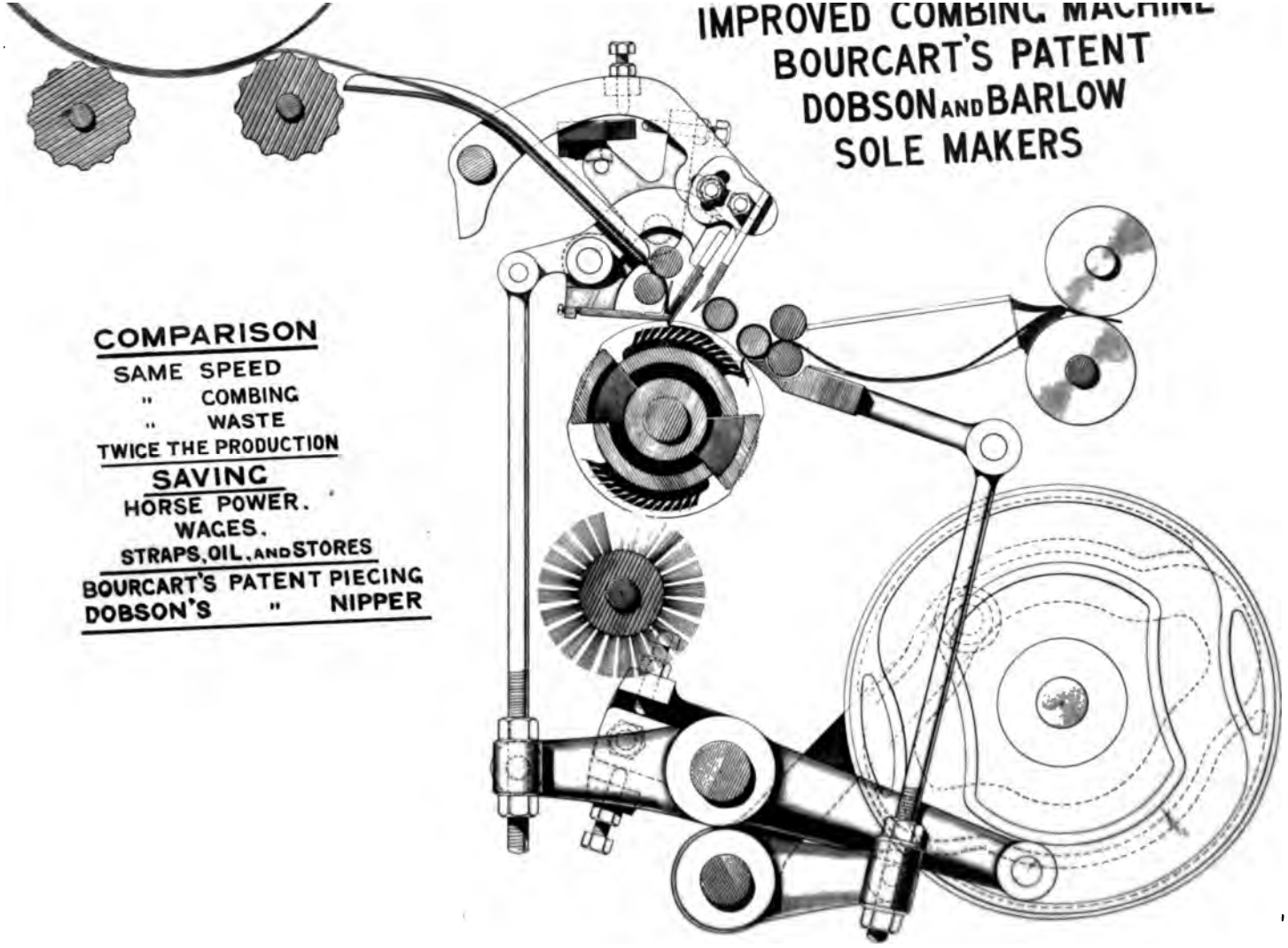
Mr. DOBSON. I am somewhat reluctant to take upon myself the direction. I know what I should do myself.

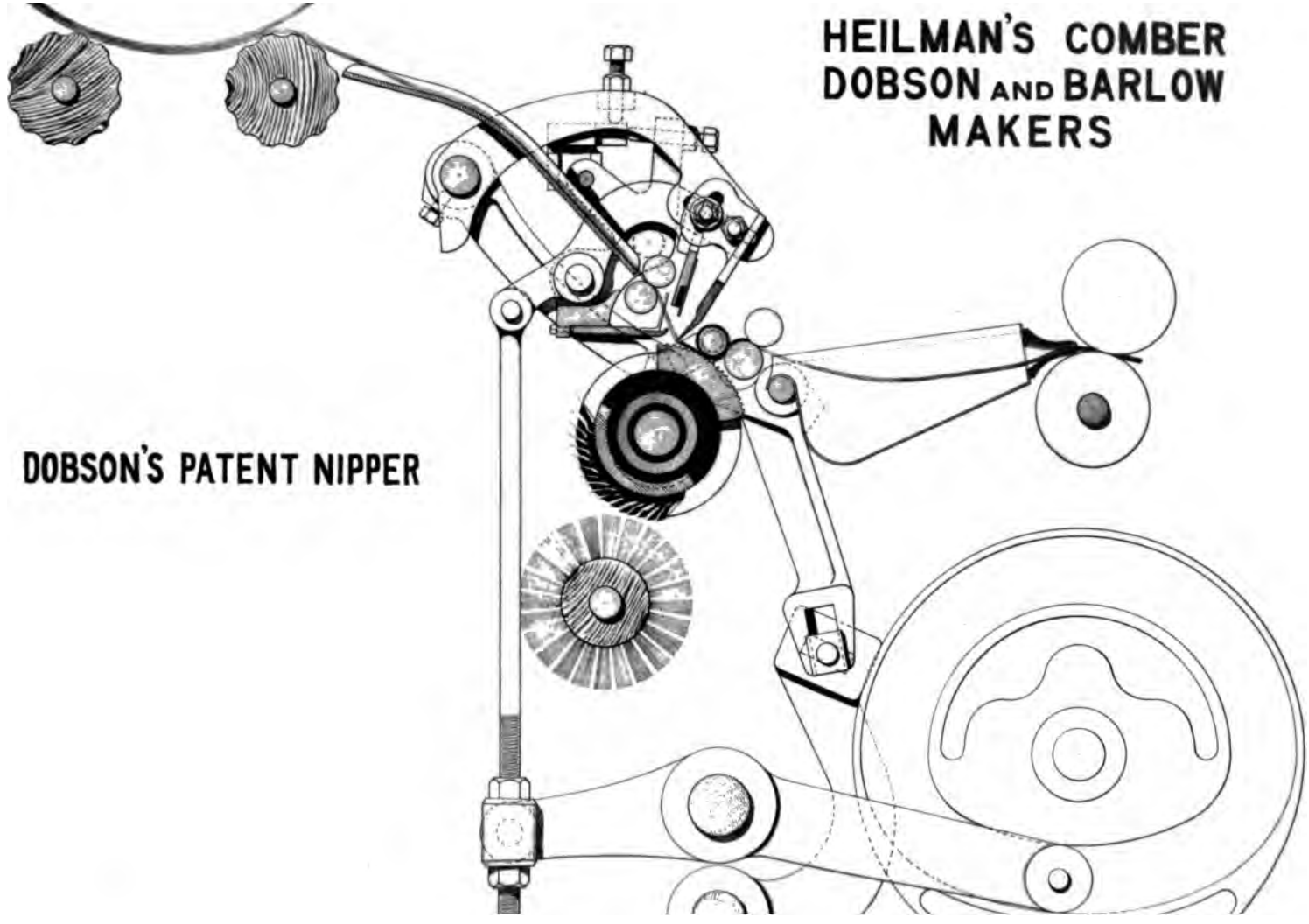
Mr. CUMNOCK. That is what I want to know.

Mr. DOBSON. [What Mr. Dobson said was not heard by the reporter.]

The PRESIDENT. The next item is the reading of a paper by Mr. ASHWORTH of Manchester, England, on "CARD CLOTHING, AND FURTHER DEVELOPMENTS OF THE ASHWORTH CARD."

Mr. ASHWORTH. Gentlemen, as joint author of the hardened-steel and needle-pointed clothing, I feel, as the man says in the play, "fairly in it," but don't you be alarmed by the exhibition of all these diagrams. They won't hurt either me or you; there is nothing at all in them. [Laughter.] Let me thank you, before I begin, for granting me the privilege of again addressing you upon this increasingly important question. Many of you will remember that I read a paper and spoke upon this subject before you last year, and took part in the subsequent discussion. I am very much pleased, indeed I am delighted, to be here to-day, and to throw whatever light I may be able upon a question which, up to a few years ago, was a resident in cloud-land or a land of mystery and com-


IMPROVED COMBING MACHINE
BOURCART'S PATENT
DOBSON AND BARLOW
SOLE MAKERS
COMPARISON
SAME SPEED
" COMBING
" WASTE
TWICE THE PRODUCTION
SAVING
HORSE POWER.
WAGES.
STRAPS, OIL, AND STORES
BOURCART'S PATENT PIECING
DOBSON'S " NIPPER


HEILMAN'S COMBER
DOBSON AND BARLOW
MAKERS
DOBSON'S PATENT NIPPER

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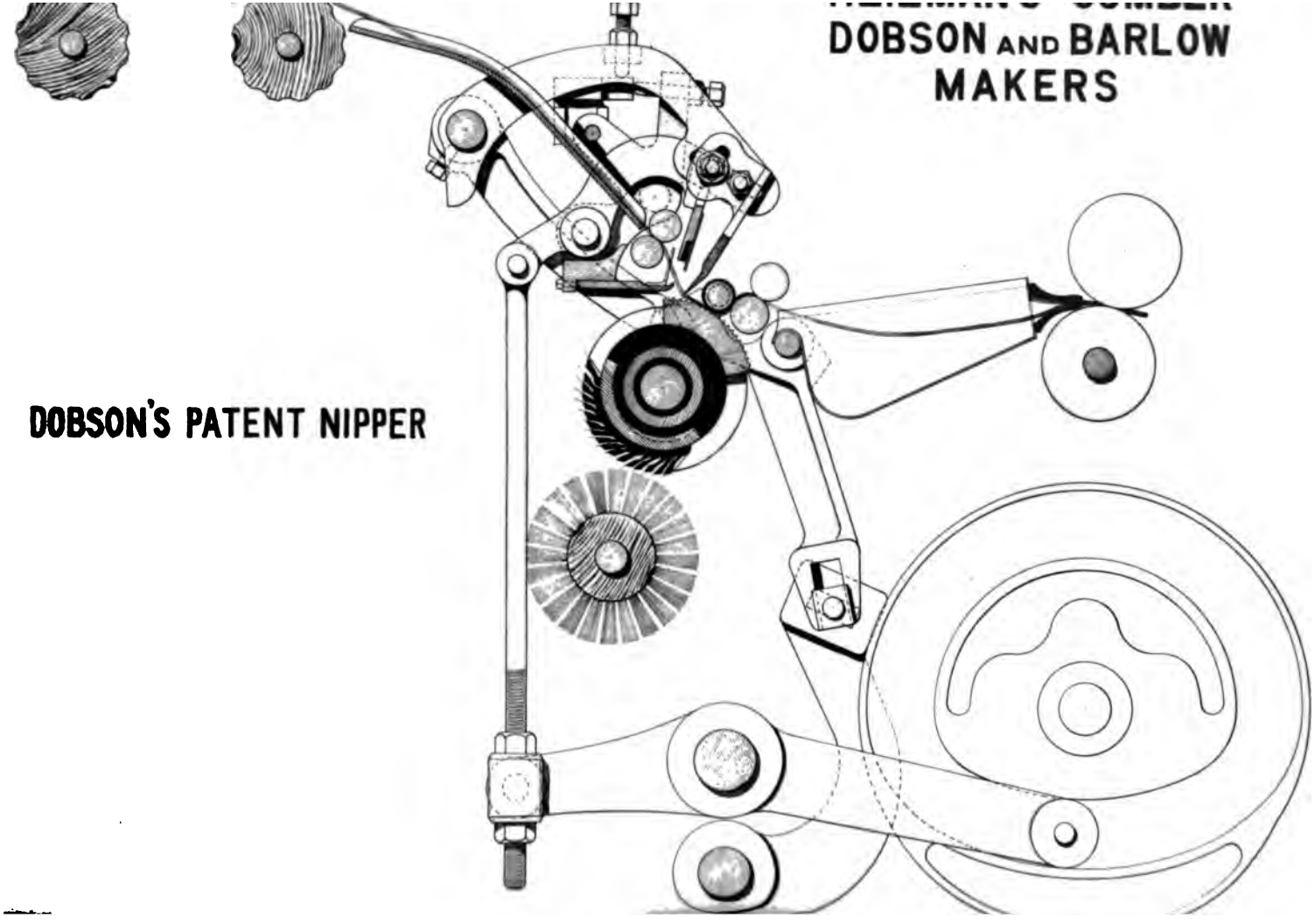
DOBSON AND BARLOW
MAKERS
DOBSON'S PATENT NIPPER

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parative superstition. I just said that I was glad to be here, and that I was here at your last meeting. Well, yes; I think I am here, but I am not quite sure. I think I am here in the flesh, that is, so far as I possess that article, but I am not sure upon that point. It is rather funny, you know. About three weeks after the last meeting a report went abroad to our people at the works, — and it made them very anxious, — that Ashworth was completely "laid out and smashed up." Well, naturally, as they wanted to see me again, you know, they were very anxious to know how the whole thing had gone on. I suppose it must be that I am a conceited fellow, or else I am very thick-skinned, but I didn't feel particularly "smashed up," that is all. And as I came last year partly to do business, principally, indeed, to do business, — don't make any mistake, I am not a philanthropist, I came here to do business, — and partly to improve my health, because I had worked very hard, I think it comes about in this way that, owing to the healthfulness of your climate, I had got so well that I was fairly convalescent and really didn't know how badly I was used or "smashed" up, and so I turned up all right at home.

And I said to a spinner the other day, well, if they "smashed" me up the last time, I have come here again, and I hope to-day that with their burning and withering criticisms they will cremate me, and then they will have done with Ashworth. [Laughter.] Then the English machine makers will reach the millennium; they will hear no more of Ashworth's notions and radical improvements, and so they will stay just where they are in regard to progress.

I wish to mention another thing, because these things are curious. A gentleman said to me a few days ago, "Mr. Ashworth, I am very glad to see you here, for there was a man here a little while ago who said that 'Ashworth is used up and worn out; that he couldn't sell a card in England, and so he has come over here to bamboozle the Americans.'" Well, that sounded very funny to me. I said, "Well, you know if I am

worn out and done up I am not the first fellow who has come from Europe worn out and cleaned out, or having cleaned somebody else out, and come over here to bamboozle the Americans." [Laughter.] Surely, gentlemen, in a country like this, — a country which has given refuge to any man and every man, a country which condones past offences and gives a man a chance to start again, you won't turn me out, so I will just ask you to let me remain. I only just say this to let you know the kind of a man you have amongst you. I intend to "bamboozle" the Americans if I can, but I want to find the man I can "bamboozle" first. I don't know where that gentleman is. I have had a good deal of experience among you, and I haven't found anybody yet with that particular weakness. I have talked with superintendents, and I have talked with treasurers, and I have talked with carders here, but I can't find they are very easy to be bamboozled. That is my first impression. I am going to be on the outlook, however, and if I can "bamboozle" anybody into buying a thousand of Ashworth's cards, I am going to do it. If I can come across a half dozen treasurers who are easily bamboozled to buy a thousand of Ashworth's cards, there is going to be a "boom" in bamboozling and I am going into it.

Now, let us come seriously to this paper, because it is rather a peculiar paper. Mr. Dobson's paper is a very long one and I intend to criticise this before I begin my own, and then I shall ask everybody to criticise mine. I don't ask you to take anything for granted, as I have told you before, but I want you to subject it to the very severest criticism. Take every sentence, take every line, every word, if you like, as we go along. Mr. Dobson begins his paper with a postscript. I am always suspicious of those things, you know. There is always something very funny about a postscript. It looks like a piece tacked on, as though the main structure wasn't quite finished and something has to be stuck on. I shall only mention this in order to clear my own position, because it seems as if I was presenting myself here oftener than I ought. Mr. Dobson

simply says: "When I selected the subject for the paper I am about to read, I was unaware of the fact that it had already been discussed more than once by your society." I only wish to tell my friend Mr. Atkinson, because I know he is a very bright fellow, that if he allowed that to go in he didn't look after Mr. Dobson's interests. [Laughter.] I suppose, Mr. Dobson, you read my paper, didn't you?

Mr. Dobson. I don't know that Mr. Ashworth has any right to address his remarks to me. Let us keep away from personalities.

The President. We will hear what you have to say about carding, Mr. Ashworth, but we do not think there is any necessity for entering into any personal matter. [Applause.]

Mr. Ashworth. All right. I wish to say — only because I wish to meet this remark about "making invidious comparisons or personal references" — that I don't consider it an invidious comparison to mention a card by the name of the maker. You are here to have the facts laid before you in the most compact form, and if I mention my card I think I have a right to name Mr. Dobson's card and say it is Mr. Dobson's, and I have a right to compare it with Platt's and say it is Platt's, or with the Whitin card or any other. For if I say my card is so and so, and such and such cards do not possess those features or do possess such merits, I leave much uncertainty in your own minds as to where and to what I am directing my criticism. You know there are cards in the market somewhere, but you haven't time to see where the points of difference are without going to more trouble than there is any necessity for. You want it all boiled down and presented to you. So I don't consider it in the line of personality if I mention Dobson's cards and Platt's cards by their distinguishing names, and if such a man or I said so and so I will say he said this thing about such a card and I will state the exact truth as far as I am able; because Mr. Dobson might as well put my name to about all of this here, for this side-grinding means Ashworth and the steel card means Ashworth, and so on through the paper.

Everybody knows we are responsible for the steel card; everybody knows we are responsible for the needle-pointed card, and that Mr. Dobson's notions are the very antipodes of our own. I say a fine point is the right thing for carding, and he goes to the very opposite.

Let me begin on page 31, because Mr. Dobson makes a statement there which I consider doesn't hold water. This word "films," for instance, is a word from my own paper. I used the word films and I take the responsibility of it. I like to be particular in the use of language, as I am a pretty fair linguist, and if I am incorrect I would like to be taught what is correct; but for the moment I will just take Mr. Dobson's notion and use his word, which is "tufts." Now, I wish to point out the very weak foundation on which he builds this structure. It is this. "For some reason the operation the cotton is submitted to in carding is generally considered to be a sort of mystery, because it is impossible to see the peculiar nature of the process at the time." Now, Mr. Leigh, in his paper, uses a different word from mine; I think he says "flakes." But we will take Mr. Dobson as right; for all I wish to protest against is this: that this distinction between these two words "film" and "tufts," or "film" and "tufts" and "flakes," is not at all fit to erect such an argument upon as that "this incorrectness of expression has given rise to ideas entirely mistaken as to the real nature of the process." That is my point. Now, gentlemen, I want to know what this all means. If this paper is right it ought to remain and everybody ought to adopt its guidance. But if it is not right — I am simply pleading for true, correct principles — let it be burned and got out of the way. If mine is wrong let that be burned. We can't afford in these days to have things complicated if we can have them simplified; we cannot afford to accumulate theories which are simply confusing. Now, let us go a little further.

Mr. Pevey. I would like to rise to a point of order. I think we are here to listen to Mr. Ashworth's paper, and not

to hear him discuss some other paper. I would like to have Mr. Ashworth read his paper, and then the discussion can follow.

The PRESIDENT. Does the gentleman wish to make a motion to that effect? If so it would be in order. Mr. Ashworth asked if he could have the privilege of making a few remarks with regard to the paper which had been already read before he read his own, and it was thought that would not be out of the way. Do gentlemen prefer to have him read his paper?

Mr. PEVEY. I make that as a motion.

Mr. CHARLES D. MCDUFFIE. I move, as an amendment to that, that Mr. Ashworth be allowed to criticise Mr. Dobson's paper before reading his paper.

Mr. A. G. CUMNOCK. Mr. Ashworth comes here as a stranger from the other side, and I hope he will have the privilege of criticising Mr. Dobson's paper; but I do hope he will avoid mentioning Mr. Dobson's name or the names of other card manufacturers.

Mr. McDuffie's motion was adopted.

Mr. ASHWORTH. You simply want me to give no names; not to mention names?

The PRESIDENT. I understand we do not care to have any acrimonious personalities here, but we should be glad to know everything we can about cards, — whether in criticism of others or in exposition of your own methods. [Applause.]

Mr. DOBSON. May I ask if I shall have an opportunity of correcting Mr. Ashworth? He has already misrepresented me once.

Mr. ASHWORTH. Certainly, Mr. Dobson; I ask it.

Mr. DOBSON. I addressed the President, if you will excuse me. [Laughter.]

The PRESIDENT. I think, Mr. Dobson, the association will have no objection.

Mr. ASHWORTH. Now, as to the value of the feed and licker-in producing so great a result, I wish to make a remark,

because Mr. Dobson lays very great importance upon the work of these two organs and the results they produce. Now, I mean to say that that is altogether exaggerated. Messrs. Platt Brothers, I am quite sure, made that taker-in and that dish feed as well thirty years ago as they do now: and, therefore, I say that that part of the paper is an exaggeration. Going on a little lower down you find a question about the roughness of the licker-in wire. Now, Mr. Dobson, — [Laughter] I can't help it, gentlemen.

The President. I think there is no objection to Mr. Ashworth's mentioning Mr. Dobson's name.

Mr. Dobson. I don't care. The more he mentions my name the better advertisement it is for me. [Laughter.]

Mr. Ashworth. I am very glad to have that permission, because it facilitates matters. That is just what we both came here for, Mr. Dobson. (I really forgot when I mentioned his name.) [Laughter.] I am glad to see that Mr. Dobson is not alarmed about the roughness of the tooth. The roughness of the taker-in tooth, the ordinary saw-tooth, is very different from that tooth. The ordinary saw-tooth is a saw-tooth in every sense of the word, — that is, it is cut out on the front side as well as the back. The two front parts are sharp, as well as the back; and if you examine that through a microscope you may depend upon it you will be very much alarmed. And yet Mr. Dobson doesn't take alarm at the roughness of the taker-in, but he says it doesn't do any injury, and in that I agree with him. I remember the experience with fixing the metallic taker-in in a mill in Bolton. As they got on they found the pillars and the beams all covered with dust, and of course they concluded the taker-in was cutting up the cotton. They were very nervous, and so they made their tests; but they found there was nothing in it. The fact of the matter was that this taker-in was so efficient an opener that it knocked and shook the cotton more, and this dust was just the result of more efficient opening and cleaning of the cotton. I only just mention that in passing, because Mr. Dobson does not dwell upon the

roughness of the taker-in, but later on he takes very strong ground about the roughness of our wire. I leave, therefore, the question of the taker-in, and proceed.

There is another point on page 40 where I join issue with Mr. Dobson: "In the first place there is quality and in the second place quantity. If quality alone is wanted, irrespective of the question of production, the same conditions do not hold good; and the same applies exactly as regards quantity. I maintain that it is impossible to get at the same time the extreme of quality and the extreme of quantity, and that as one increases the other suffers. In fact, this is an axiom or principle that is universally applicable, not only to carding but to almost everything else." Well, I deny that altogether. [Laughter.] You take two men in a work-shop, and you find one man doing thirty per cent. more work than another, and you will find that man does the best work. If you will go even higher, — if you will go up even to the fine arts, — and take Rubens who painted so many yards of pictures. Look at the work he did, and yet look and see how finished it was! And the higher you go the greater is the difference; it is all a matter of efficiency. There are card wire makers here, and they know quite well that one man looks after twenty machines; and they will tell you that they have men who are minding sixteen and other men who are minding twenty-four machines, and the men who are minding twenty-four produce as much work again as the men who are minding sixteen, and the work is better. The point is this, that quantity nearly always means quality. Given efficiency, and you will have the quantity as well as the quality.

I mention this because I know this is a hit at the great productions we have given out as possible from our card; and I wish to say that that machine does the work, and it is also high in quality. I wish also to simplify this matter about the saw-tooth. I mean to say that there is no necessity at all for going to anything different than one form and angle of tooth. I place this thing in a nutshell. You may strike a line right through the centre of the taker-in, and make the front part of

the tooth coincident with that line (other things being equal), and that taker-in will do for every kind of work; and you needn't complicate this point of the question at all. I give that as the result of very careful experiments.

I should be very glad if I could find out from this paper exactly what Mr. Dobson recommends, because he says wire "may be made" of either iron or steel. Of course we expect he has some opinions, and we desire to know exactly what he recommends. But I can join issue with him in what he says on page 41, because this is the point and this is the theory which are the very antipodes of our own. We say—and I am here to stake our reputation upon it, and I ask you to remember it—that a "fine point" is the best for carding. You need not go any further than that. You need not complicate it with this wire or that wire, this shape or that shape. If you can get "fine points," other things being equal, that is the right thing for carding. Now, there it is boiled down for you. We start on that, and if that doesn't go through you will see me go off out of this country, and you will never hear of me again speaking upon this great question.

Now, just look at this. Mr. Dobson means to say from this sentence that the action of the emery roller serrates the ends of the wires, and naturally the carding is done on them—that is, by these "serrations." That is a very curious theory to me. If that is the case, why not increase the thickness of the wires? Then you get more "serrations" and you get more carding. Of course you have less space for dirt. Now, I am very anxious to impress upon you that this is a theory which I want you to remember, and I want Mr. Dobson to have the full credit of enunciating this theory, because either I am wrong or he is wrong, and this new theory may bring him undying fame. I say we don't want any end surface at all, but "fine points," and he says in effect we want end surface, because the carding is done on these end surfaces or "serrations" on end surfaces. On page 42 he says: "It is better in carding to

have a point which only has a serration caused by grinding the extreme top, and by this means cleaner and smoother carding can be got." Now, further on we get the objections against the side-ground wire because of its roughness. I confess it is rough, but I can't gather from Mr. Dobson's paper exactly what he means, because in some parts of it he speaks as if the roughness was quite an advantage. I should be glad if he would just enunciate clearly his position there. For instance, he says on page 45, —

"A difficulty of side-ground wire is the stripping of the flats, and when a card has been started it has often been found necessary to put a metallic brush, instead of the ordinary bristle hair brush, to smooth the teeth of the flats sufficiently to allow them to strip. When this brush has worked a certain length of time the flats will strip almost as easily as any ordinary wire, the meaning of it being that, by its constant revolution in the wire of the flats, some of the asperities caused by the side grinding in the lower part of the point have been removed. When this result has been obtained the carding is found to be irregular and dirty, and further side grinding in places is found necessary."

Now, I don't know, I should be glad if Mr. Dobson would make a note of that and tell me what he means by "further side grinding in places is found to be necessary." We never saw any such need. We finish the pointing at the mills, we get all the teeth perfectly level, and we get, of course, the finished points. I don't mean to say but if I could smooth the wires I should. I think, — I don't use a strong phrase, — I think it is a right thing to have smooth wires. I agree with Mr. Dobson in that. I simply want Mr. Dobson to tell us exactly what he means by this language. In some places it seems as if he were speaking against rough wires, and then he speaks in favor of the rough wires.

There is another point on page 41. Passing over all this (because I have tried my best to understand all and can't really get hold of it), I come to this because it is a result which is said to be due to the roughness of the wires: "In dyeing

delicate shades and light tints some parts of the yarn will take up more of the coloring-matter than other parts, and give an uneven and blotchy appearance to the piece. The reason of the extra dye being absorbed is, of course, the fact that the fly acts similarly to a sponge." I have been looking for this ever since I saw this paper, but I can't find it. It is a very curious thing to me that, taking 40s, in these days of close competition, you can sell yarn which has so much roughness on it as to act "similarly to a sponge," and you don't know it is caused by your wire. Can this be caused by the roughness of this wire when the metal is so hard that the revolving brush won't take off the roughness? You see what an infinitesimal amount of power there is to be brought over from this "roughness" of the wire, when, in making yarn 40s and 50s, it is so rough that it "acts similarly to a sponge." Notice; this yarn is so rough, and yet the buyer only finds it out when dyed. I know some experts in yarn, but I am quite sure this is information to them; and I should like to hear what they have to say about that. I can assure you that wherever we have these wires at work the yarn is smooth and regular, and there is no complaint.

If you will excuse me, Mr. President, before I go on I will finish up this subject by just reading one or two letters on this point. One is from a firm which I am quite sure Mr. Dobson will not question as to their ability to judge and as to their integrity to say what they think is right. We built 140 cards for the J. & P. Coats, Paisley, Scotland, for carding fine Egyptian cotton, and for ever so long after these cards were working it was reported that the roughness of Ashworth's wire damaged the fibre so much that they couldn't use the yarn and put it on the market. This was often denied, and yet people kept it up. Well, just before I came away there was an order for carding engines to be given, and the man who was competing with me, as a parting shot, fired at the spinner this report, and he then sent me this letter. At the end of it he says, —

Is there any truth in the report, mentioned to me this week, that Messrs. Coats could not use the yarn carded from your hardened and tempered steel wire for some considerable time in consequence of the wire damaging the fibre, and that the yarn was sold in the Manchester market?

Knowing the importance of this I immediately wired Coats to this effect: —

PAISLEY, March 26, 1888.

To Messrs. Ashworth Brothers, Manchester.

The following telegrams were exchanged to-day: —

1. "A machine maker, to influence an order, reports: 'Coats could not use the yarn carded from Ashworth's tempered steel wire for some considerable time, owing to roughness of wire damaging fibre, and that the yarn was sold in Manchester market.' Have given exact quotation from letter sent us; please write us reply to-day."

2. "Telegram received, report not true; are writing to-night."

In reference to the above, you can give this report the most unqualified denial in every particular. The carded yarn we made for a short time, through being short of combers on account of Bolton strike, was first-class and superior to any we were getting. So far as we have gone your cards have given the most complete satisfaction, and we would still put them in if building a new mill, as we are not aware of any superior to them.

In regard to our selling yarn in the Manchester market, we thought this childish story was exploded. The only foundation for such a report that we can think of being the fact that a few cops were extracted from our place at the start, and perhaps sold to some jealous parties who had an anxious solicitude for our success.

Yours truly, J. & P. COATS.

I think, gentlemen, there is hardly another firm better able to judge of yarns than this one, and I think they wouldn't give such a letter as that if they found anything at all like ooziness in their yarn. I have a telegram here, — I will finish this point off now I am on it. I wrote to the Globe Yarn Mill, Fall River, where we put in forty cards, and asked if they found any ooziness or dulness, and they say: —

GLOBE YARN MILL, FALL RIVER, April 25, 1888.

Letter received. Carding from your engines brighter and better than from ours; mild steel clothing in mills numbers 1 and 2. Production, one thousand pounds and satisfactory.

A. B. SANFORD.

I will leave that part of the subject and go on, because it is very likely that there are plenty of gentlemen here who have knowledge of the Ashworth cards, and there are also agents of card makers here, and they can tell something as well as I can about the needle-point. There is a great deal more in Mr. Dobson's paper that I could criticise, but some of the matters I went over with you last year and so I will not refer to them again, but will now read my paper.

CARD CLOTHING.

In the discussion which followed the reading of my paper on carding, etc., before your Association in October last, some remarks were made and questions asked respecting the essential features of the best card clothing. Though I had done my best to lay down the essential forms of structure for the best clothing, deduced from scientific premises, as the result of many experiments, I was not in the least surprised that on a many-sided question like this — one which, during the last three years (owing to so many attempts at advancement), has become somewhat complicated — a number of doubts should exist as to the truth of the premises laid down and the deductions made therefrom. Moreover, I had asked to have my positions contravened at every point, because of the great value of legitimate *viva voce* discussion in bringing out the truth, especially when under the eye of an audience so keenly practical and critical as the one then before me. The great extent of ground traversed by the paper, and discussion, at the last meeting prolonged it to such an hour, however, that I had not the chance to make such a reply to the criticisms of the points I had advanced on card clothing as was due to the importance of the questions asked and the objections urged.

As these questions and objections have more in them than is seen at first sight, and open out much that is interesting, I wish (before proceeding to deal with the more important parts of my subject to-day) to return for a short time to this matter of card clothing. Let us, for a few moments, glance at the counts and kind of clothing which you have used, and, I presume, are still using on your make of cards, because this will lead up to the questions raised in the recent discussion. I find that your clothing for cylinder seldom has more than 64,800 points to the square foot set with 33s wire; for doffer, 72,000 points set with 34s wire; flats, — especially those nearest the feed roller, — with fewer points still. Now, compare these counts and grades of wire with such as we use to clothe our own cards; and as all these inquiries are to obtain the highest practical result, let me state that the cards so clothed are giving the best production ever seen or heard of, both as regards quantity, quality and little cost in waste and labor.

In addition to this they will work equally well the lowest Surat or the finest Sea Island cotton, such alterations only being made, in relation to quantity carded, draughts, speed, etc., as may be found desirable. Now this is a most important and suggestive fact to note. It proves, I think, conclusively, a statement made in my former paper that certain "theories, and the practices built upon them, are the results of defective construction of the machines and other appliances to do the work." It is most astonishing how much a piece of technical work becomes circumscribed or centralized if there be a scientific substructure or foundation. Among spinners in England, and no doubt in America also, as many variations as there are days in the week have existed in regard to counts of wire to be used, as well as other differences in methods of practice, to produce the same yarns from almost the same class of cottons; and now we have proof that no such variable practice is necessary to give the best possible result. The clothing we use for our cards is all hardened and tempered steel, ground away from bend upwards, — "side reduced" as we term it, — and

finished to fine points by hand process at the mills, after the card has been clothed and ground up in the ordinary way. The cylinder we clothe with our 110s equal to 79,200 points to the square foot, 32½ wire; doffer and flats 130s equal to 93,000 points to the square foot, 33½ wire. In some cases we use ten counts finer all round. Notice that with 14,400 more points to the square foot for our cylinder clothing compared to yours, we still employ half a size thicker wire, — your points being 64,800, wire 33; ours 79,200, wire 32½. About the same disparity exists throughout, but this one example will serve my purpose for illustration. It is not my intention to contend that your clothing, with the number of points and thickness of wire as cited above, is not the best for your make of cards, — that is, those without taker-in. I am inclined to think such a clothing is the best for your present method of working. Whether, with the side or back reduced wires, such as can be supplied you to-day, and as many points as we use to the square foot, a better result would not be obtained even on your cards without taker-in, is a matter which we hope ere long to have some opinions upon.

Mr. E. W. Atkinson, in last year's discussion, asked me "whether we did not cut away our wires down the sides, in order to increase the space between them, that the cotton would the easier enter instead of riding on the top of the wires," and I replied in the affirmative. Receiving this reply, Mr. Atkinson proceeded to give us some figures to prove how small an extra quantity of space could be gained, even supposing we cut away three-fourths of the wire contained in a square foot of clothing, assuming the clothing to be such as you use for your ordinary American cards. He gave as his example such a clothing as you often use for the cylinder, — one having 64,800 points to the square foot, set with 33 wire. He made out that in the 144 inches of such a clothing there were but four inches taken up by the wire. Such being the case — provided that we cut away the wires only to increase space, or obtain clearance as we term it — Mr. Atkinson could

well afford to be generous and give us the full benefit of our process. Allowing us the credit of being able to cut away three inches of the four taken up by the wire, the record would read as follows: 144 square inches of clothing, original form 140 inches space, four inches wire; altered form (by Ashworth's process of reducing the wires), 143 inches space, one inch wire surface; gain of space in one square foot, three inches only.

Now, with only mention of the fact that the space taken up by the wire in a foot of the clothing now in question is practically quite double that which has been stated, I am prepared to prove my case by taking the figures given. Mr. Atkinson at one portion of his criticisms informed us that he was not an "expert" of the subject under discussion; still he began to speak of certain points which none but an expert should approach. His remarks upon this part of our subject prove the truth of the old saying, — "a little knowledge is a dangerous thing." When I replied in the affirmative to the question "whether we did not reduce the wires in order to get plenty of room for the cotton to lay in," the questioner, concluding that that was *all* we gained by our cutting-away process, immediately fired off a volley of figures with which he had armed himself. Now, if Mr. Atkinson had only thought over the subject a little, or condescended to talk a little with some sharp American carder on the features of card clothing, grinding the same, and the results of his practice, he might have known that beyond the question of space between the wires "for the cotton to lay in" there are several others equally or more important, — the power of penetration of the wires on account of the fineness of the points; and their power, or efficiency, to face and do certain work, owing to their strength at the root, etc.

Apropos of fineness of point, or power of penetration, a very little advance in this direction always gives quite a disproportionately good result. Any practical carder will tell you that of two cards clothed in the same way the one which

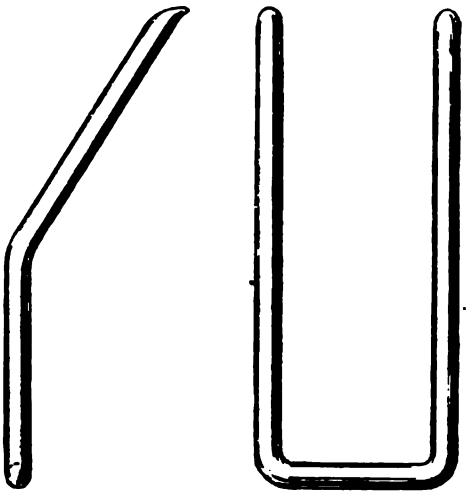
has been ground a little more carefully than the other will give a much better quality of work; and yet a very careful examination will be needed to find out the difference in the ends of the wires of the two. In order to lay this part of the subject more clearly before you, allow me to reproduce that part of my former paper in which I laid down the principles of construction of the best card clothing. This is given as, — "that card clothing which, having the same number of points to the square foot as another, has the smallest wire-end surface and the greatest space between its wires for the entrance of the material, with an equal or greater strength of the wires at the root; such card clothing to be so constructed as to retain the first-named conditions (fine points or small wire-end surface) as long as possible with the ordinary grinding treatment in use at the mills." You will notice that four essential principles of construction are laid down in order to construct the best card clothing: the required number of points; small end surface or fine points; plenty of space or clearance between the wires; and the greatest strength of wire at the root. Now any make of clothing which has these four features of construction in the proper proportions, allowing a retention of them with ordinary mill usage, is unquestionably the best.

To illustrate my meaning more clearly let me refer to a question asked at one of your previous meetings. The question was "Will a needle-point card?" Now the idea in the mind of the questioner is plainly, I think, — "Supposing you can have a cylinder clothing 72,000 to the square foot, set with 33s wire, hardened and tempered, ground perfectly smooth and tapering to points like needles, will this cylinder fillet card?" If such a clothing could be produced to have all the wires exactly the same length when on the cylinder, I have no hesitation in saying that it would not only card, but produce the best carding ever yet seen, other things about the machine being equal. Such a clothing, however, could not be made save as a fancy thing. The cost would be prohibitive, and any grinding in the usual way at the mills would soon cause rapid

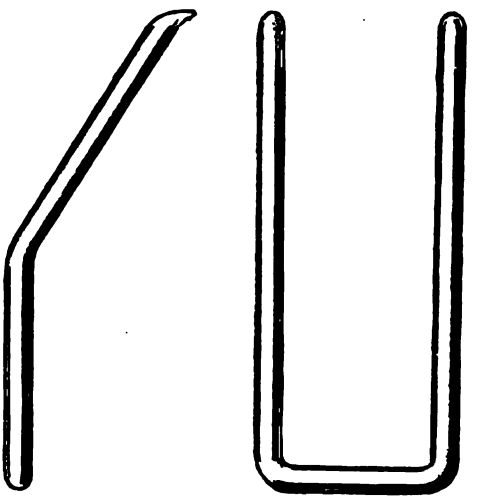
depreciation unless the wires were tapered down to the bend. It would have the three first qualities but not the last. Take now the question of space, or "clearance," between the wires. A cylinder clothing such as you use, 64,800 points to the square foot, might be set with 40s wire, say, — for the sake of argument, — and you would have plenty of space or clearance and less wire and surface; but there is not the strength of the wire at the root. Hence, the wires through weakness would fall away from their work when faced with the cotton, would quickly be ruined by stripping, and very poor carding would be the result.

Not to prolong this part of my subject, let me say that I am convinced that such a clothing as you use — few points and fine wires — is not the right kind in my opinion, supposing you have the proper machine; and would not give a result such as we are obtaining from our card to-day. My answer, therefore, to this part of last year's discussion is that to get more space is only *one* of the reasons why we cut our wires away; there are several others equally or more important. Of these we place first the power to use clothing with a large number of points to the square foot; a stronger wire than otherwise would be possible, and hence greater strength at the root; finer points than are now got, even with careful grinding on much finer wires; and such fine points producible by ordinary mill grinding. In leaving this part of the question let me remark that in any measurement of the space taken up by the wires in a square foot of clothing, at least twenty-five per cent. should be added for the "hook" which round wire carries more than any other form. This is an objectionable enlargement of wire-end surface, and cannot altogether be prevented by the most careful grinding exercised at the mills.

We here give you large views of round card wires: No. 1 carefully ground and No. 2 badly ground, much hooked; also a form of tooth which will make the best carding and give the highest results yet known, as far as clothing is concerned, if such a tooth in hardened steel can be produced.



No. 1



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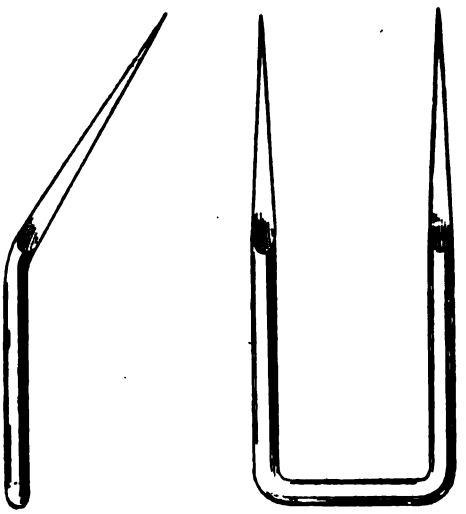

BEST FORM OF TOOTH
FOR CARDING

Features of the Card.

Owing to the length of my last paper I was forced to compress it towards the end, and it will be remembered that I merely named several novel and valuable features of construction which the card possessed. Even to-day I must content myself with giving as short a description of two only of the improvements then named, with a fuller description of two recent additions, both of which are of great value, and will, I think, when understood, so present themselves to your minds. The first is our

New Construction of Card Cylinders.

This new construction of carding engine cylinder consists in its being moulded in longitudinal halves, with the portions of star wheels cast in the ends of each part of the half circles. Strong flanges run along each end of the halves of cylinder.

These flanges, and the arms of the "star wheel," are milled at one operation; the former tongued and grooved; the tongued part of one fitting into the grooved part of the other. By the use of eight very strong and well-fitting bolts on each side, along the whole length of these flanges, the two halves of the cylinder are firmly secured together. The cylinder thus constructed is then put into a special boring machine, and the holes at each end are bored with the same boring shaft at one operation. These holes are thus made perfectly concentric to each other, and exactly the size of the cylinder shaft. That part of the halves of the "star wheel" arms adjacent to the holes, having been milled one sixty-fourth inch lower than the flanges, gives sufficient binding power for the holding bolts — two on each side of the hole — to firmly secure the shaft in its position in the cylinder. The old plan of moulding cylinders is by the use of a collapsible core shaft, or mandrel, covered with loam or clay to form the exterior. This core is then fixed in the centre of a circular hole — made by a strickling board, or in some cases by iron pattern — in a pit, or moulding-box, to give the outside form to the cylinder. The great difficulty of daubing the loam equal in thickness over every part of the core bar, so as to get a true inside, and then, even if true, to fix it quite in the centre of the circular hole, — this being necessary to get a casting of uniform thickness, — will be quite palpable to any one possessing the least knowledge of the subject. As a matter of fact, many card cylinders made in this way, when turned up and finished, are quite double the thickness on one side compared to the other. The total finished thickness is usually about $\frac{9}{32}$ of an inch, and if examined they will often be found to have $\frac{6}{32}$ of an inch thickness on one side, and but $\frac{3}{32}$ of an inch on the other. With such a difference in thickness it is not only impossible to turn up and finish a cylinder fairly true, but there is sure to be some loss of power also to the card in which such a cylinder is put to work. Another serious fault of this plan of making cylinders is the internal and unequal strain or tension existing in different parts of the casting,

arising from the difficulty of cooling every part in exactly the same space of time. This internal strain is always present in all cylindrical castings, and is well known to all practical men. It is evidenced by the breaking of the arms of pulleys,—even when these are made of an "S" shape to minimize the evil,—and other castings of like form, at a very long period after these articles have been put to work. A spinner, who has over 200 cards at work in his mill, asked us the other day to give him a reason why the main cylinders of his cards, after ten or fifteen years' use, should be now so much out of truth. He stated that "almost all were found much out of truth and balance, and yet they were fairly true when the engines were started."

We believe that the above fault, with the method of building up the cylinder ends and fitting in the shafts, furnishes a reply. In the ordinary plan of building up a card cylinder there are six joints or surfaces, which have to be tooled and trued by machine: first, the end of the cylinder; second, the rim of the star wheel end, which fits in the cylinder; third, the holes in the cylinder end, or "star wheel," as it is called, into which is fitted the conical split bush (this hole is conical); fourth, the outside of conical bush; fifth, inside of conical bush, which is parallel; sixth, the surface of the cylinder shaft. This is parallel, and is held in the cylinder by the split conical bush being driven tight into the hole of the star wheel, or cylinder, end. To a person acquainted with the nature of cast iron, and the management of tools and men, not much argument will be needed, if indeed any, to convince him of the difficulty in getting all these surfaces quite true. It is impossible to make all these surfaces so true that there will not be unequal strain in different parts when the shaft is secured by the conical bush being driven home. This difficulty is acknowledged in the practice of sending away card cylinders with their shafts fitted in. Makers know quite well that if the shafts were taken out after being fitted in, as above, and the cylinders turned true from them, there would be many chances against their going in

again exactly as before. By our method the halves of cylinders are moulded from an iron pattern made out of a smooth rolled plate of an equal thickness. The thickening ribs on the inside of the pattern, as well as the arms for the ends, are all planed and of equal weight. No cores are used in moulding. Both the inside and outside of the mould for the half cylinder, also the ends, being formed by carefully smooth and balanced iron pattern, the castings come out exactly of an equal thickness. An examination of the internal surface of a cylinder casting made with core, and a comparison of it with the internal surface of any one of our castings, will prove at once the value of the new plan. The internal surface of a casting made with core is rough, ragged and unlevel; showing at once that the casting must vary considerably in thickness. The internal surface of the one made from the iron pattern is quite smooth and level, the lines and bevels of the thickening ribs being quite clear and distinct. We have weighed several of these cylinder castings, and find the most unequal to vary only two pounds in a five hundred weight casting. These cylinders, therefore, being of equal thickness, require few balancing weights, and are finished to seven-sixteenths of an inch. This thickness, with a uniform body of metal, enables us to turn up and finish a cylinder to be as true and circular as is possible with the best tools and careful manipulation. This cylinder, being built of two longitudinal halves, is freed from most of the internal strain or tension largely present in all cylindrical castings; and hence there is no danger of card cylinders of this construction altering their shape, or working themselves out of balance and truth by a few years' use. These cylinders having the ends cast in, with the holes bored exactly the size of the shaft, and this shaft secured as explained above; there are only two surfaces — that of the parallel hole in the cylinder end and the shaft — to be dealt with. Those, with the special machines we have designed for the work, we can get quite true. The important result is that there is no unequal pressure on any part of the shaft or hole in which it is fitted. After

one of these cylinders has been finished we can take out the shaft and replace it, without the least risk of throwing the cylinder out of truth. Now, all the shafts are taken out of these cylinders, packed carefully and separately in a box, and replaced at the mill. A very slight knock will throw a shaft out of truth when fixed in its cylinder, and it is next to impossible to send one any distance without its receiving much rough usage in transit. This plan of construction, therefore, enabling us to send the shafts carefully packed in a separate box, is, for this reason also, very valuable.

Automatic Oiling Comb Box.

The next piece of mechanism to which I shall but briefly refer is our patent automatic oiling doffing comb box. The box we had on our card at the Boston exhibition last year was much admired for its design, good workmanship and steady working; and we now have an addition to that. To get 1,000 pounds of carding through an engine in fifty-four hours' working, and often needing a doffer 24 inches in diameter to run 18 revolutions per minute, the doffing must be powerful above its work. We run this comb at the rate of 4,000 inches per minute with very steady action. To run this immense speed without deterioration, the points of construction and workmanship must be of the highest class. All the working parts in this box have good bearing surfaces made of cast-iron, and every piece is carefully surfaced work. For the oiling, conduits are cut in such directions along all the frictional parts that the oil fed into the box flows along each part where it is needed, out through a tube, into a hollow cylindrical box or reservoir. This box is attached to the spindle which works the motions in the box, and so revolves with it. From this quickly revolving motion of the hollow box the oil which drips into it is thrown by centrifugal force against the outside. A piece of pipe bent at a right angle is screwed into the top part of the comb box, about two inches above the outlet pipe named above. This right-angle bent piece of pipe is turned, with its end or mouth upwards, inside

the revolving box carrying the oil, just to clear the rim inside the box; and in such a direction that the oil is driven by centrifugal force and the power of the box's revolution through the angle bent — or feeding pipe, as it really is — back again into the comb box. The oil is poured into this box down an oil hole, which is always closed up when the card is at work by means of a long spindle screwed into it and reaching to the bottom. This spindle answers the double purpose of closing up the oil hole to keep out the dust and is also a gauge to test when more oil should be poured in. The bottom part of the spindle which dips into the oil is marked off in distances. By drawing out the spindle, wiping it dry, putting it into the box and then withdrawing it, the depth of oil then in the box will be marked on it. These boxes will thus run quite three or four months with one supply of oil. Another feature is, that not a drop of oil works out. None is therefore found trickling down the sides of a box, a serious fault and common to all others I have so far seen.

New Driving for Card Cylinders.

Owing to a statement made in last year's discussion I showed a drawing of, and explained, our new driving for card cylinders. That method answers its purpose very well; but I bring to your notice to-day a still better method to effect the same end. By this new plan the cylinder is freely revolved in its bearings without being subjected to the slightest pressure from any driving strap. All side wear of the cylinder bearings, or straining of the shaft out of the direct line, is prevented; as well as any alteration in the shape of the holes from round to such an elongated form as would interfere with a perfectly steady turning of the cylinder, or allow it to move its position in the bearings to the detriment of that "close set" between the various parts of the card, which is necessary to secure and retain the highest result. The elongation of the hole of the main cylinder bearings comes from two well-known causes: first, the side pull of the driving belt; and secondly, the weight of the

main cylinder and its tendency to wear or work its way in the direction of motion.

Another evil, not so well known, but still always present and causing much greater damage than is ever imagined, is the unsteady motion of the main cylinder — should there be the least play in the bearings — when putting on or driving with an extra tight strap; especially when the pulley on the driving shaft is directly, or nearly, over the one on the main cylinder of the carding engine. Considering, therefore, how essential is the steady working of the cylinder, in order to procure and retain the desired close setting between flats, doffer, taker-in and cylinder; and how, with the old plan of driving, the required "fine set" is often prevented, owing to a tight strap, an irregular or lumpy piecing, or the direction of the pulley driving belt, etc.; this new method which removes these difficulties will, we feel sure, be fully appreciated when once seen and understood. This method of driving, which is fitted to both sides of the card, is effected by the use of a boss five inches in diameter, the same width as the card-driving pulley, and having a square flange on one side for the purpose of screwing it to that part of the card bend in which the cylinder bearings are fixed. This boss, after being turned perfectly true both inside and out, with its flange finished at right angles to the periphery, is then screwed, by means of the above-named flange, to the outside of that part of the card bend which carries the cylinder bearings; through which, at each side, the cylinder shaft ends, which carry the pulleys, project. These bosses having been screwed to the frame sides, so that the circles represented by the turned parts shall be perfectly concentric to the ends of the cylinder shafts, it will be seen that, when the card is working, the cylinder shaft ends revolve inside of them. On these turned bosses which have been screwed to the frame side the driving and other pulleys rest and revolve. Every pressure of any strap, therefore, is received by these stationary bosses; and in whatever position

the driving strap be, — standing right overhead, or at any other angle, — the pull or pressure of the strap is not in any way communicated to the cylinder shaft. The driving pulley having to work on the stationary boss, must of course be bored its diameter, — namely, five inches. This pulley has a recess $1\frac{5}{8}$ inch by $\frac{1}{2}$ inch deep, planed across its outside face of the inside rim — that next to the boss. The next piece is that by which the revolution of the pulley is communicated to the cylinder. This consists of a clutch or double armed boss three inches long, fitting the cylinder shaft and having a key way planed in its length. This armed boss is connected with the cylinder shaft, by its key way, through the key way let into the end of the shaft; and, therefore, any revolving power communicated to this armed boss will revolve the cylinder itself. The strap turns the driving pulley fixed on the stationary boss. The pulley's revolution is given to the armed boss by the latter being slid on the shaft until these arms go into the square recess of the driving pulley; and so the cylinder is driven. The driving on the other side of the card is arranged on the same plan; and so the cylinder shaft there is also freed from the pressure of taker-in and other straps. There can be little doubt that this is the correct method of driving the cylinder of a card. It is no argument to say that the old plan has not shown itself to be defective. A careful examination would show it to be very faulty; and the evil results of it would have been found long ago if people had known how and where to look for them. These and a few other faults of the same kind were the cause of the old revolving flat cards producing hitherto only about 400 pounds carding of American cotton in the same time in which our engine of to-day is producing over double that weight. Evidently there have been many changes somewhere. Some of these changes are like our new construction of carding cylinder already described. Whilst not seemingly great in themselves, in the aggregate they mean the attainment of a large result.

The last improvement to which I shall call your attention to-day is our

Patented Method of gauging and adjusting to a Perfect Concentricity the Internal Circle represented by the Wire of the Flats with that of the External Wire Surface of the Main Cylinder.

This is one of the most valuable developments of this class of card ever introduced, and I solicit your careful attention to it.

To be able to determine (at any time during the life of a revolving flat carding engine) by the expenditure of only a few minutes' labor, when the internal circle line represented by the wire of the flats is *perfectly concentric* with that of the wire surface of the carding cylinder, is a power which we are quite certain every practical carder has often wished for and felt the need of. If to this power of easily determining the position of these two circles, in relation to each other, could have been added that of easily adjusting them to be *perfectly concentric*, it is hardly conceivable with how much pleasure the careful manager, carder, or student of carding and cotton spinning, would have welcomed this new power which had thus been placed in his hands. During our own labors and researches in connection with this important operation we have often felt the need of the power we now mention; and since we began to make and offer carding engines, have always felt dissatisfied with ourselves when replying to the question so often asked, "How can you tell when the two circles are concentric?" that we had no better answer to make than, "By adopting the general method,—that of pressing on a flat here and there round the cylinder when the card is at work, in order to judge of its distance from the revolving wire surface," etc.

Such, indeed, is the method which has been generally adopted for determining the set and concentricity of the flats of a revolving flat card since the day it was introduced up to the present time. Any one who has studied the subject knows

quite well that this plan is but a "rule of thumb" process—a groping in the dark, comparatively, or sort of guessing distances method, rather than knowing by a positive gauging and measurement. Many times have we heard of practical men complaining of the unsatisfactory result of their labors expended in setting the flats of this particular card; and although something more certain has often been anxiously desired, it has not, up to now, been produced. A little thought will show good reason why a positive means of determining the distance and concentricity of the flats in relation to the carding cylinder has not until now been discovered. A scientific plan of setting such as we now present, in connection with our own card, is not possible with any other, all of which have their bends, on which the flats slide, made as separate pieces, and attached to the frame sides; the circle of which bends are expanded and compressed by "setting screws;" which "setting screws" are often fitted with discs, worm and wheel, etc. The present "rule of thumb" method of setting the flats and determining their distance and concentricity in relation to the cylinder surface, when the cards are at work, has been so far used, and will continue to be, on all cards like those named above, because in setting them no other plan can be employed. According to an old physiological law, "like produces like"; and the same thing is true in mechanical science. Error produces error. Given an unscientific and erroneous mechanical construction, and an uncertain, faulty and "rule of thumb" practice is the result. With the circles on which the flats slide attached to the frame, and compressed or expanded by their six or ten "setting points," there are several obstacles in the way of employing any other means than that now adopted, viz., pressing on several flats round each side of the working cylinder, to determine their concentricity and set. It is quite impossible for any one, however skilful, to take in and let out all the six or ten "setting points" exactly to give the same expansion or compression of the "bend." Neither does the employment of discs afford any

positive knowledge of how much the bend will be expanded or contracted at a certain point when the card is fitted up for work, and all the *weight of the flats is on the circles.* Add to this the irregular wearing of the bend itself on account of varying pressure on certain parts, — the trouble caused by complication through the necessary use of so many joints; the deflection by the weight of the flats between the "setting points," — and the need of determining the concentricity and set by pressing on several of the flats around *each side of the cylinder* is at once made plain. With this construction, and its inevitable plan of setting, each side of the bend may have a different relation of eccentricity to its own side of the carding cylinder; hence, the necessity of trying to determine the concentricity in the manner already explained. Nor would anything be gained if the carder went to the trouble of taking off a few flats, at several points, around each side of the card, and set at each point to a gauge; simply because the bends, being "flexible" (having so many joints, "setting points," etc.), are placed by vibration, and a certain strain caused by revolving the flats, in quite a different relation with respect to the cylinder surface when the card is working, from that in which they are found when the machine is at rest. By adopting the method we now offer, any chance of the two circles being eccentric, or an indefinite "set," is reduced to a minimum; indeed, perfect concentricity can be secured, and from this a definite distance-working "set" can be given to *every flat* round each side of the cylinder by gauging *one flat only* (any one on the top of the bend) and setting it, while the card is at rest, at the proper distance from the cylinder wire. In order to obtain this measurable concentricity and retainable close "set" for every flat round the cylinder, and to secure this with little labor at any time during the life of a card, we must have true and unalterable foundations or premises to build upon; and to these true and unalterable parts or premises we must be able at any time to return with facility, and take our "soundings" or measurements. If my description

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of our "non-flexible bend," given in last year's paper, can be partly remembered, it will the better enable you to understand my description of this plan of gauging the concentricity of the two circles. I will, however, describe it so that I think it will be understood; especially as I shall at the end of this paper exhibit it by drawings.

Revolving flat carding engines, until the invention of our card, were always built up of *three pieces*, viz., the pedestal for carrying cylinder bearings, the frame side, and the "flexible bend." In our own machine *only one piece* is employed, *i. e.*, the frame side being made to answer the three-fold purpose. This frame side, after being planed for the purpose, and fitted with the special metal cylinder bearings, which are bored to template, is then turned, on the top to form the path on which the flats slide, and on its outside for the purpose of attaching thereto the various brackets, from a mandrel fitted in the hole in which the card cylinder works. After this, in order to make *perfectly true* the section of the circle on which the flats are to work, the frame or "bend" is put into a special grinding machine; being mounted on a hardened and trued steel mandrel, fitting exactly the hole of cylinder bearings; and from this is ground as true as a template; and, indeed, each bend, when finished, is fit to be used as such. A little thought on the above construction will show that we have now finished the top of the frame on which the flats slide to a perfect section of the circle, which circle must be concentric to the mandrel on which it has thus been finished; and concentric, therefore, to the cylinder shaft which is to work in the same hole, as well as concentric to the main cylinder itself.

It will now be necessary to refer back to the "stationary bosses" used in connection with our new driving already described. These "stationary bosses," it will be seen, are screwed to the frame sides, and the ends of the cylinder shaft project through the inside of them. Outside, these bosses are turned for the driving pulleys to work upon. They have inside, contiguous to the outer edge, a narrow projection; and

this is bored to a certain templet size. In securing the "stationary bosses" to each side of the frame we use a double gauging template,—"he" and "she" in one,—the outside of which is stepped with ten sizes or diameters. The largest of these diameters fits the inside of the bosses; the inside fitting the ends of the cylinder shaft. We fasten the bosses by screws and then secure by steady pins; so as to have their insides perfectly concentric to the cylinder shaft. Now we have shown that by construction the cylinder shaft-ends, and, therefore, the cylinder, are concentric to the section of the circle on which the flats slide; and as the insides of the bosses are concentric to the shaft-ends, they must also be, therefore, concentric to the sections of the circles of the bends. The sections of these circles, with the insides of the stationary boxes, now secured to be perfectly concentric to them, form our method of testing concentricity; and these are the *unalterable premises*, or truly fixed parts, to which we can at any time easily refer to take our soundings and measurements.

All our cards when sent out, before any wear has taken place in the cylinder bearings, will be found to have the three circles—the "bend," or path on which the flats travel, the inside of the stationary bosses, and the cylinder shaft,—therefore the cylinder surface—*perfectly concentric* to each other. Having now the essentially primary conditions, or trued, fixed parts, we can at any time make the most perfect set possible between the flats and the cylinder. Using the double gauging template, we put this on the shaft ends, and press it forward until its largest diameter enters the inside of the stationary bosses. This proves the concentricity of the bends, or wire surface of the flats, with that of the main cylinder. The circles of the bend must now be graduated by using the required thicknesses of the steel ribbons, until we have the flats, or *one particular flat*, over the top of the main cylinder; because now this represents the whole series at the closest possible working distance. The three parts used for gauging are unalterable, because they are not working parts. There cannot there-

fore be any wear upon them; and they will remain the same in relation to each other as long as the card exists. The tops of the circles, or bends, are protected by the hardened steel ribbons; the inside of the "stationary bosses" is never touched by anything save the concentricity gauges; and that part of the cylinder shaft ends on which the gauge is placed is not subjected to wearing friction.

Owing to the employment of our new driving, the "bends" in relation to the cylinder can become eccentric in two directions only, — either through the cylinder having fallen, from some wear of the bearings, or on account of its having been raised by using the pedestal screws; for we shall employ these latter up to a certain point for setting, as explained in my last year's paper. We have now, however, brought science to our aid. By its light we can tell exactly how the vital parts of the card stand in relation to each other, and so be directed in our practice. Not only do we know now whether one circle is eccentric to the other, *but we know how much, from what cause, in what direction; and can read off the exact amount* on the testing or indicating gauge. This gauge, it has been stated, has ten sizes or diameters, each differing in size progressively by $\frac{1}{500}$, and each step, or half a diameter, $\frac{1}{1000}$ of an inch. Now, a movement of the pillar pedestal screw of one line on the disc raises the cylinder $\frac{1}{1000}$ of an inch; also the tempered steel ribbons used for altering the diameter of the "bend" vary in thickness from each other $\frac{1}{1000}$ of an inch — that is, a ribbon No. 23 is thinner by $\frac{1}{1000}$ of an inch than a No. 24.

For the sake of showing how these scientific premises produce a reliable practice, let us suppose a case where a carder has, when starting one of our cards, made as perfect a "set" as the varying deflection of the flats, owing to internal strain, will allow, — such a "set" as we have described above, graduating the circles in almost infinitesimal quantities by the use of the tempered steel ribbons, until all the flats are the nearest possible working distance from the card cylinder. In working

this card, say for twelve months, the carder has found it necessary to turn his pedestal screws, raising the cylinder four lines as indicated by the disc, — that is, $\frac{4}{1000}$ of an inch. Now, if this man has grasped the science of our method, the fact of his having to turn the pedestal screws (and thus raise the cylinder these four lines) will tell him that in this twelve months' working of the card one of two things has happened, — either the bearings have worn four lines, or a portion of this quantity; or the wire of flats and cylinder have been ground away so much, or a portion of it. To determine this, he takes the pulleys off each side of the card, and applies the concentric indicator-gauge, which at once shows him what has happened. If the bearings have worn the distance of the four lines which the pedestal screws have been raised, the largest diameter of the indicator-gauge marked "concentric" will, when slid on the cylinder shaft, enter the "stationary bosses" just as it did when starting the card twelve months ago; and will prove, as then, that the two circles are perfectly concentric. The four lines which the pedestal screws have been raised in this case compensate for this amount of wear which has taken place in the cylinder bearings. If wear of the wire of the flats and cylinder clothing, or a portion of each, has taken place to the extent of the four lines, size or diameter on indicator-gauge No. 4, only, will enter the "stationary bosses"; and the projecting ledge of size No. 3 will impinge on the *top part* of the "stationary bosses." If the bearings have worn two lines, and the wire of cylinder and flats the other two, size or diameter No. 2 of the indicator-gauge will enter the bosses, and the ledge of No. 1 will impinge on the top of them. In the same way, if any wear of the cylinder bearings should ever take place in any other direction, this wear can always be known by a few minutes' examination. There is no longer any need of speculation as to how much the wire is being ground away, or how much the cylinder bearings are wearing, because it can all be determined easily; and hence it will be seen that this method gives an immense power to the carder, by indicating

what is taking place in the most vital parts of the machine during its working. To prevent this most important portion of cotton-spinning machinery from falling into the state in which it is so often found, — a state once described by a practical cotton spinner as one of "seemingly unredeemable and not-to-be-understood complication, with the consequent loss and bad quality of production," — this method, we are quite confident, will be of exceeding great value; and when properly understood, no doubt will be regarded as a great advance towards the most scientific carding

Before drawing this paper to a close let me ask your attention to the practical result of the combination in one machine of our many improvements in cards and carding appliances,— of which only the principal ones have been explained, — as exhibited in the new small model card of which I now invite examination and criticism. The idea of making a small card had been slumbering in our minds for some time before I visited your country in May last. On account of what I saw at that visit, and as a result of conversation with a few of your cotton spinners, the small card idea received an impetus and was put in hand. Though we never had a doubt in our own minds as to the result this card would produce, we always make a point of gaining knowledge from our own and other people's experience, before giving stated results for any machine we produce and recommend. Many people would not credit on our word, without the proof of actual test, that a machine, standing in about two-thirds of the space of the modern revolving flat cards you are now working here, would produce at least 30 per cent. or 40 per cent. more work. It is most difficult for practical men to believe that of the two machines, each well made, and to a casual eye seemingly of the same construction, the first will turn off almost one-third more work than the second, of quite equal quality. As, in this instance, moreover, the greater production is obtained at half the expense of labor and attention in comparison with that spent upon the small result, one might as well expect a person to put away his ordinary busi-

ness judgment as to give credit to such figures without the proof of actual experience. Within the last three months these cards have been put to work with even a better production than this; and hence we have the proof from experimental test which we required; and so can give you our word upon the results to-day. The space in which a modern card stands, one to card a lap from a 40-inch wide picker, is given, on a circular of the machine agent, as 10 feet 4 inches by 5 feet 10 inches over all, with full lap of cotton in. This card of which I now speak, to card the same width of lap, stands in a space, over all, with full lap of cotton in, of 8 feet by 5 feet. One takes, therefore, about 60 square feet of space, and the other 40 square feet. Instead of a cylinder 50 inches in diameter we have one but 40 inches; and a doffer 16 inches in place of 24 inches. This card carries 112 flats each, with $1\frac{1}{16}$ inches width of wire; of which 44 are in operation. The taker-in is 9 inches, like the one on the large sized card. We are making these cards $44\frac{1}{4}$ inches wide, to work a 45-inch lap; that is, a lap from a 50-inch picker; 37 inches for a lap from a 40-inch picker; and 33 inches wide, to card a lap from a 36-inch picker. This latter card will stand in about the same space as one of your small American cards; and will produce 800 pounds of excellent carding in sixty hours, using low middling cotton; grinding of wire twice each year; stripping cylinder and doffer three times each week. At last year's discussion it was suggested that such large productions were not advisable, because, having regard to quality, such productions could not be kept up. It will be remembered, however, that the speaker put his proposition on this head in a half-doubting, very uncertain way, like a man not knowing his subject; or, knowing it, feeling that he could not with safety recommend such a result from the machine he had in mind; knowing at the same time that he could not with truth deny such productions from the Ashworth card. It was an attempt at seeming wise by saying nothing, or equal to nothing. Nothing was expressed but a number of doubting ideas, which would serve the double purpose of leaving an

opportunity afterwards, if such and such things came forth as results from the card represented, to recommend such productions as were then in question on the one hand; and, on the other, if my statements of what our machine would produce in this country should turn out a *fiasco*, give him a chance of going to the unfortunate users of the Ashworth cards to express his grief and sorrow at their unfortunate position, with a solemn shake of the head, meaning "I told you so"; reminding them that they had been timely warned against believing in exaggerated results, etc. In my statements as to the quantity which one of our cards will produce I was very positive and confident; and every new trial gives fresh proof that our confidence has a solid foundation. I do not consider that there is any necessity for a man to make doubtful statements, or feel his way, if he knows his subject. True science knows no doubt. It is the guiding light; and hence there can be no groping in the dark as to results. We have worked in scientific lines throughout for our improvements in clothing, and in the machine itself; and so know what will come forth as the result of our labors. I therefore appear before you to-day with fresh assurances that my statements as to production, and the little labor required to keep the cards working, made at your last meeting, can now be verified by an additional number of users. This being the case, what can be said of the so-called "high price" of the Ashworth card? This we contend is not a fair way to put the case. What will the card do for its price, and what does its work cost, compared with that of any other machine? These are the proper tests of dearness or cheapness. For a given weight of yarn we can do the work as cheaply as any other firm, indeed at a less price; especially with the small model card, considered in its proper light. We put in a less number of engines; but a spinner wants them only on account of their capacity for work. Our motto is "efficiency"; condensation, so to speak, not quantity. What spinner wants 60 carding engines if he can have his cotton quite as well carded by 44 or 46? Would a business man prefer to employ, say,

nine men to do a certain amount of labor for one hundred dollars, if he could have the same work done by six men for the same money? Experience teaches also that the quality of the work in the latter case would be better than the former, because the extra quality comes from superior skill, care and therefore "efficiency"; and "efficiency" in such cases means quality.

Consider, now, for a few minutes — providing my assertion be true as to the capacity of this small card for work — what a great saving would be effected in some of your mills by its adoption. Let us assume the quantity of yarn required per week of 60 hours is 50,000 pounds; counts 32s warp to 44s filling; cotton fair middling. Let us take the 33-inch wide card, which stands in a space, over all, of 8 feet by 4 feet 8 inches, and works a 34-inch wide lap made on your 36-inch picker. Seventy of these small 33-inch wide cards would give the weight, allowing ample for waste, for the 50,000 pounds of yarn. Only two men would be required to do what stripping, grinding, and oiling is needed; and supposing the cards to be in one room, and take up two rows, the back row being against the wall: the total space taken up for these cards, allowing full working passages, would only be 206 feet by 22½ feet; or equal to 4,635 square feet. To do the above work with 37-inch wide cards, those working laps from 40-inch pickers, about 62 cards would be needed, and would in two rows occupy a space of 187 feet by 22½ feet, or equal to 4,207 square feet. If the cards 44 inches wide to work laps from 50-inch pickers were used, 52 would do the work, and these would stand in a space of 179 feet by 22½ feet, or equal to 4,027 square feet. If you will compare the figures here given, the number of cards to do the work, the comparative space taken up, the immense saving in labor,—which is the most costly, viewed in the light of its disturbing influence on the uniformity of production,—you will see the question is a large and pressingly important one. Let me give you another comparison, which is interesting because it is against the famous

"Oldham double card," sarcastically called by a cotton spinner of my acquaintance the "Oldham double elephant." One of these to work a lap from a 50-inch picker would occupy a space over all of 15 feet 2 inches by 7 feet 5 inches, or equal to 112 square feet. To produce 60,000 pounds in 54 hours, cotton and counts as above, 70 of such cards would be required, taking a space in room, — two rows, — with working passages, of 299 feet by 36 feet 6 inches, or equal to 10,913 square feet. These would require 12 strippers and grinders. Sixty of our small model cards would do the same work, give a better quality of production, and occupy a space only of 206 feet by 22½ feet, or equal to 4,635 square feet, two men would do all the stripping, grinding, oiling, etc., and not more than one-tenth of the oil, strapping, etc., would be required when compared to the former case.

I here beg to name the most remarkable thing ever experienced in connection with cotton spinning. A mill in England has 65 of our 44-inch wide cards, producing 78,000 pounds of yarn in 60 hours. The yarn is 20s to 40s, cotton about low middling. These cards had worked, when I left, three months, and not a single cylinder or doffer had in that time ever been stripped. The yarn, also, is the best possible quality.

Again, let me now ask your free criticism of this small model card upon its own merits, taking for the present no heed of the pessimist prophecies which have already been uttered on both sides of the water respecting it. One machine maker in England has been very industrious already in reporting that "Ashworth has just come from America and brought a small model card, a type we have tried and discarded years ago." Your western breezes have also wafted across to us such expressions as "absurd," "ridiculous," and the like as applied to this idea. With respect to the machine maker named above, — our discarding friend, — I just wish to remind him through this paper that "discarding" is his strong point, for he is compelled to discard more than he can afford to stick to. As to this idea being "absurd," or "ridiculous,"—

well, we shall see what we shall see. We are quite used to these polite expletives; because the like, and much stronger expressions have been used in connection with every step of progress we have taken. There is an old saying, "never prophesy unless you know." My last part of this paper shall be a prophecy, nevertheless. This "absurd" card will be as phenomenal a success as anything we have ever introduced, and the pessimist prophets, before twelve months have passed, after having spent a large amount of power to keep it out of the market, will do as they have hitherto done, be compelled to turn round and follow, doing their utmost to copy, without, as they think, falling under the lash of the law.

Mr. Ashworth with the aid of a full-sized model then explained the new driving and concentric testing method.

Mr. Dobson. Will you tell me if that driving is Dugdale's patent?

Mr. Ashworth. Yes. It was offered to us, and we bought it.

Mr. Dobson. It was offered to us, and we didn't.

Mr. Ashworth. Yes, I know, and to Hetherington also; and while you were thinking about it we bought it over your heads. [Laughter.] Unlike many firms, Mr. Dobson, we either invent or *purchase* an invention. Nearly always we invent our improvements. If out of consideration for us you left Dugdale's patent I thank you earnestly for it. We are glad we bought it; you are pleased you didn't. Both are happy.

Mr. Alfred Clarke. We have listened to Mr. Ashworth and to Mr. Dobson on this matter of carding, and the results have been given to us in the first person singular. I have done this and I have done the other, they say. I object to this, inasmuch as I think it ought to be "we." Now, I think the lapper manufacturers have something to do with these excellent results that are obtained by the English carding. I would like to know, and I would ask of Mr. Ashworth or of Mr. Dobson, whether the results obtained from these cards

would be the same, providing the laps varied two ounces? Of course I don't believe there is any American manufacturer of lappers who would allow a variation of two-tenths of an ounce. At the same time I would like to ask them what part the picking and preparation of the cotton plays in the results obtained from these cards; and, also, before Mr. Ashworth sits down, I should like to have him tell us what particular system of picking he recommends to obtain the results that he claims from his card.

Mr. Ashworth. I don't know anything about picking, and I will leave that to Mr. Dobson. Mr. Dobson understands it and I don't, and I never speak on a subject I don't understand. [Laughter.]

Mr. Dobson. You are kind enough to allow me the opportunity of speaking in reply to Mr. Ashworth. I shall not detain you very long, for I am very hungry. [Laughter.] But Mr. Ashworth misunderstood me if he imagined I said at any time the cylinder was covered with tufts of cotton, applying that word as mine instead of films. I did my best to make it clear that there were very few fibres in the working part of the cylinder at any one time when the card was at work. I don't know as I care to follow what Mr. Ashworth has said. I am perfectly willing to let my paper stand against his paper and the remarks he has made, and allow the judgment of individuals to decide what is right. I do not profess to perform any miracles, and I do not profess to be infallible, but I gave as far as I could my own ideas, and you will see from what I have done that it has not been hurriedly done, but that it has required a great deal of thought. I will say that I may back up my own opinion by this report, which is taken from *L'Industrie Textile*, which is published in Paris, — the December number, 1886. I will read the closing paragraphs, for I think it will substantiate my opinion, and Mr. Ashworth may find it advisable to pay attention to it, if not to what I say.

Speaking of the Ashworth card clothed with side-ground wire, it says: —

It seems to break the fibres, especially the longest ones; because after the card has been running a short time all the polished surfaces become covered with an impalpable powder, a sort of fluff coming from the broken fibres. Also, the different experiments made on this card go to show that it gives a greater amount of invisible waste than cards with fixed flats. We have likewise noticed that if the sliver from the Ashworth card is examined at the second head of drawing it will have more neps in it than that from a mixed card.

The reduction in waste that this card gives reaches its maximum on Egyptians at 1 per cent. But if this same Egyptian is put through the comb it gives more waste.

Trial made on Egyptian (fully good fair): —

	Kilo.	
Cotton entering,	69.61	
Sliver delivered,	66.74	
Waste,	2.87	

Of this, —

		Per cent.
Measurable waste,	1.860	2.67
Invisible waste,	1.010	1.45
Total,	2.87	4.12

The same cotton passed through a mixed card (2 rollers and 10 flats) gave a waste of 5.03 per cent.

This would indicate 9–10 of one per cent. in favor of the Ashworth card. Now passing both these slivers through the same comb and comparing the results we have the following: —

Preparation from mixed card, total comber waste 18.216 per cent.; preparation from Ashworth card, total comber waste 21.903 per cent.

Thus the Ashworth card gives 21.903–18.216=3.68 per cent. more waste in the comb than the mixed card. The gain of 1 per cent. waste in the card is a poor compensation for the 3.38 per cent. loss in the comb.

This result which has been many times substantiated corroborates what we have said regarding the breaking of the long fibres passing through this card.

Now that is to be accounted for in some way. Either the cotton contains short fibre that ought not to be there if the

carding is properly done, or else it has injured the cotton to such an extent that the comber has failed to take it out. There is no getting out of that dilemma. Every cotton that is grown, unfortunately, has a certain amount of short staple in it, and your cotton, perhaps, has more than what we use on the other side. I find our Egyptian cotton runs evener than your American cotton at present does. I suppose you will improve the breed of it by and by. It is evident that either the waste is left in that ought to be taken out, or that the fibre is weakened; and I will say before I sit down, that if there is any object of interest to you gentlemen in getting cotton of equal fibre and of full length you will have to alter your gins in the South.* I made a calculation once, with the help of some very celebrated men in England who have studied this thing, and I got samples, so far as I could, of the cotton grown in the southern States of America. I have forgotten exactly the figures, but if I remember right we calculated there was a loss in staple of something like $9,000,000 a year to the South from the use of a saw gin. As regards the picking, I find that in most of the mills I have been in the cotton has far too much done to it. I think you hammer your cotton to death before you allow the card to get a chance at it.

Mr. Edward W. Atkinson. I didn't expect to be drawn into this discussion at all to-day, but Mr. Ashworth has treated me a little severely, I think, in the first part of his paper, and I would like to ask indulgence for a moment or two only, to make a reply. Mr. Ashworth advises me very kindly to condescend, as he puts it, to talk with some sharp, practical, American carders. Now, it has always been my practice, and I am always very glad to talk with any practical carder, and I have often done so; and it was the result of many such practical talks that I asked Mr. Ashworth the question I did. And I am very glad to find that "the volley of figures" which he says I fired at him have hit the mark so well. Mr. Ashworth has made a quotation in this connection. He says, "A little knowledge is a dangerous thing." Mr. Ashworth has taken

the trouble to come all the way from England to make a quotation from an English poet; and I should think he would have taken pains to quote correctly. You all know Pope's famous line is, "A little learning is a dangerous thing," and I think you couldn't have a better example of it than in the quotation that Mr. Ashworth has attempted to make. [Laughter.]

Now, Mr. Ashworth would lead the readers of this paper to infer that I know nothing of my subject. I wish to say for Mr. Ashworth's future knowledge that I have spent a very considerable time and had a very considerable experience in setting up, grinding, and starting and running both cards and mules, and other machinery of our American make; and I see a prominent agent of one of our best mills here to-day who, I think, would be very glad to attest that fact if Mr. Ashworth does not care to take my word for it. I have found that our American mills are conducted according to the laws of plain common sense, rather than by following out any complex theory; and I would like to say to Mr. Ashworth that I consider myself quite as competent to judge of results, and quite as competent to tell that two and two make four in cotton spinning, as he is.

Mr. Ashworth. May I say a few words?

The President. If no one objects.

Mr. Ashworth. I am very much obliged to Mr. Atkinson for correcting me about a quotation. I have not had a college education. I had to scramble for my education, and I got most of it between the time I was twenty and thirty. I don't profess to be a poet authority, and I don't profess to make my quotations true to the letter. At the same time I am always glad to be corrected by an authority, although I don't see that it makes very much difference in the sense in this case; still, I like to have a correction. I came here for correction, and I am thankful to Mr. Atkinson for pointing out this error; and I thank him also for raising the question last year, because I wanted to get the matter still further before you and bring out what, through his criticism, I have brought out. I have no

doubt Mr. Atkinson has a good knowledge of cotton spinning, as I think I have of carding; therefore, don't think I said this from any personal feelings in the least. I simply wanted to know what he had to say. I asked you to contest every point with us. You know exactly what positions I take on these questions, and you know exactly what is the result of all these improvements. "The exigencies of the trade," which Mr. Dobson has talked about, mean the exigencies of the trade through the production of the Ashworth card. I am very much obliged to you, gentlemen, for giving me your attention.

Mr. CLARKE. I would like to ask Mr. Ashworth one question. He has recently introduced a 36-inch English card in competition with the 40-inch cards already introduced, and I would like to ask him what advantage he expects to get over the 40-inch by the 36-inch card; and if the 36-inch card is an advantage over the 40-inch card, how much a 30-inch card would be an advantage over a 36-inch card to the manufacturer.

Mr. ASHWORTH. We are prepared to make cards of any width, to begin with, and if a mill-owner has all his pickers and driving pulleys in his mill arranged for a certain width of card we could put in cards to correspond. There are some mills where they have pillars so arranged they can put in a wider card, and in that case the man would, I have no doubt, take such a one He gets the most carding in the least space, for rather less money, with the wider card.

Mr. CLARKE. I was talking with a manufacturer who has the 36-inch carding, and he says that Mr. Ashworth claimed it was at a loss of only one-seventeeth of the carding in the mill, while the 40-inch card was an addition of one-ninth more machinery, — that the difference in the carding, taking the same square inches of carding-surface, was only one-seventeenth. Is that correct?

Mr. ASHWORTH. I don't know, sir. I can't give you any further reason why I put in these narrow cards, except as a matter of convenience, owing to the construction of the mill.

Mr. Leigh. As I have been the means of placing, directly or indirectly, nearly 1,500 Platt revolving top flat cards in this country, I must reply to some of Mr. Ashworth's remarks.

I said at the last meeting that I did not believe in the Ashworth card, and gave my reasons therefor. You will remember I told you that it would be found impossible to keep the cylinder exactly concentric with the bend; this Mr. Ashworth practically admits by what he has shown you to-day. He has done away with the two guide pulleys, described in his paper at last meeting, intended to prevent side wear of the cylinder bearings, and now shows you another method of accomplishing this object by the introduction of two bosses, held by the card framing at each side, five inches in diameter, upon which the fast pulley and pulley for driving licker-in revolve, still retaining the screw for raising cylinder pedestal in case of wear downwards.

I do not think it will require much discernment from any good mechanic to see how complicated and expensive this new plan is, or to calculate the extra power required to revolve these two pulleys over a boss five inches in diameter, to say nothing of the extra oiling and care that must be given to keep them clean.

A bearing of this description, covered up as it must be by the pulleys, and exposed to the dirt and dust of the card room, cannot fail of itself to be a cause of great trouble. Suppose it should by any chance get dry and gall, what would be the effect? You could not get the pulley off, nor could you get at the boss, for it is fastened behind the pulley to pedestal or bend; so I see no other way than to draw the card framing apart in order to get the pulley and boss off, and probably this is the reason he purposes making the cylinder in two parts, so that in case of an accident of this kind he can the more easily take the card to pieces.

I will not dwell upon the other points made in his paper, such as the proper way to make card cylinders and doffing combs, but will simply ask Mr. Ashworth how it is that if his card is

the great success he claims that he has not done more business with it in England, where it has had a longer trial than anywhere else, and if it is not true that he is now making fewer cards than he was doing a year ago. For a short time, some years ago, he held the attention of manufacturers abroad by the extraordinary statements and claims he made, and it seems to me even here he is following the same line of action which he did in England; for you will remember it was only at our last meeting that he recommended a card with fifty-inch diameter cylinder, and now, six months later, he recommends one with forty inches.

I have it from very good authority that he has only had one of these forty-inch diameter cards at work in England since February of this year, and that its dimensions are the same as he has given you, the cylinder running about 230 revolutions per minute, the doffer 16, the licker-in 700, and the production of the card, which is 45 inches on the wire, is 800 pounds per week.

Now, I ask any reasonable man if Mr. Ashworth or any one else can tell the future of this small card or any other card on so short a trial.

We all know the experience in this country with cards that have been brought out within the last ten years.

I have in mind four different models, and I think I am within the bounds of truth in saying that all these four different cards have failed to beat the old Wellman card so generally in use.

These cards had a run of several years, and at first were more or less successful; but time has shown their defects, and where are they to-day?

I hold that neither Mr. Ashworth nor any one else can tell at the present time what will be the future of his card. Certainly two years or five years will not tell; it will take ten years, at least, to develop its merits or show its faults.

As regards adopting cards thirty-four inches wide, as now

recommended by Mr. Ashworth, the following figures will show the fallacy of this idea: —

Suppose you wish to card 10,000 pounds per day, your cards, with new openers and lappers, will cost say $70,000; if you had cards only thirty-four inches wide you would require thirteen more of them, which would cost, without the openers and lappers,, $65,000, or, say $5,000 less; to set against this, you could get $1,000 for your present lappers if sold for old metal; you save 1,280 square feet of flooring at eighty cents a foot, which equals $1,025, reducing the first extra cost to $2,975, and you make an annual saving of sixteen horse-power, which at $50 per horse-power equals $800, and at least $780 in wages (as you have two finisher lappers and thirteen cards less to drive and attend to); making an annual saving of $1,580.

You would have many other advantages, — less belting, less oiling, less cleaning, etc., — besides being able, in making the change, to avail yourself of the latest improved picking machinery.

It is all very well for Mr. Ashworth or any one else to show a sample card, from which can be got extraordinary results, especially if clothed with needle-pointed card clothing, got up by hand to a very fine point, but I hold, as I have said before, that this fine point cannot be maintained in the ordinary running of mills, either in this country or any other, as the point of the wire must of necessity be ground off, and the carding will depreciate accordingly.

I would like to ask the question of Mr. Ashworth, if he knows of any first-class mill in England, or elsewhere, that was filled with revolving top flat cards ten years ago, made by any other maker than Platt, where the orders have been duplicated? my object being to show that the recent makers of revolving top flat cards have not tested their cards sufficiently to prove their superiority.

Time may prove them to be all that the makers claim, but I fail to see why you should go past a machine that has stood

the test of experience, and that can be seen in operation any day in some of the best mills ever built in this country, producing results certainly equal to any others, and surpassing many of them.

This machine, as now running here, will pay any one from twenty to fifty per cent. on the outlay, if put in over the common Wellman top flat card.

As I have stated before, Messrs. Platt have had a very long experience with revolving flat cards, and they do not contend that the machine has yet been brought to perfection, but on the contrary are always making experiments themselves, to see how the machine can be improved; and they have recently made some improvements in the way of better grids or undercasings for cylinders and licker-ins, and have also been able to reduce the width of their card six and one-half inches, by making the flats four inches shorter and putting the bends inside of cylinders instead of outside as formerly; i. e., the cylinder runs over the top of the bend, thus answering the objections of some critics, who claim that their form of card made side waste, and that their flats being longer were weaker.

They have also improved their stripping box covers, making same so that they must now be set concentric with the cylinder at all stages of wear of wire.

While I do not contend that other makers than Platt cannot bring out new improvements, I know that many changes that are made are nothing but changes and not improvements, and if the makers had had the extended experience of thirty years, which the Platts have had, they would make no claims for improvements that had not been well tried and found to be of great value before they were brought out and recommended the public.

I am bringing out some of the new pattern cards above referred to, and in the course of a few days you will have an opportunity of seeing the new machines at work.

Mr. ASHWORTH. Judging from the opinions of a few present that paper was bordering very dangerously near to the "personal"; but I don't mind it in the least. I like it very much; it simplifies matters, and I thank you for it. There is plenty of my name in that, and I am pleased; it simplifies things. In the first place, I think we are making more cards than we ever were before. That settles that question. Very shortly, I dare say, we shall make as many as our friend does. As to the second point —

Mr. LEIGH. Let us have the truth.

Mr. ASHWORTH. I will tell you.

The PRESIDENT. I don't think that is a question the meeting is very much interested in. [Applause.]

Mr. ASHWORTH. I was about to answer his second question. We have one card at work here in the Pacific Mills, — a small one, — doing 900 pounds. I have three letters in reference to small model cards here. One is from a gentleman Mr. Dobson knows, Mr. Thorp, of Messrs. J. J. Hayes, Leigh. They have three hundred cards at work, of our needle-pointed wire, and they won't touch anything else. I can give you a half-dozen other people who have two or three hundred of our cards at work. There is only one opinion about it, and that is that it must go. You mark that, and don't you forget it. I will read you these letters: —

VICTORIA MILLS, LEIGH, WEST MANCHESTER,
March 5, 1888.

To MESSRS. ASHWORTH BROS., *Manchester*.

GENTLEMEN, — The two forty-inch (small model) cards are at work. They are an improvement on the fifty-inch. Yours truly,

JAMES THORP.

LOW MOOR-CLITHERO, ENGLAND, April 7, 1888.

MESSRS. ASHWORTH BROS., *Manchester*.

DEAR SIRS, — We are eminently satisfied with the small model carding engines you have made us, and infinitely prefer them to any cards we have ever seen. We are, Yours faithfully,

THOS. GARNETT & SONS.

HURST, April 7, 1888.

MESSRS. ASHWORTH BROS., *Manchester*.

DEAR SIRS, — As far as I can judge from the time it has worked, your small engine is perfectly satisfactory in every respect.

Yours very truly,

OLDHAM WHITTAKER & SONS.
per WALTER ROWLEY.

Now, gentlemen, I don't think I need say anything more to take up your time.

Mr. EDWARD ATKINSON. I have a suggestion to make, not with reference to the discussion, which, unfortunately, I did not hear. I have, however, read the papers printed in advance. I think you are now likely to get a true idea of the essentials of carding. You may remember that I have said to you on my return from each visit I have made to Europe that you would not get a thorough test between the American carding system and the English carding system until you had the mechanical conditions equal, and the construction of the cards equal; that, when you had an American card made with the exactness (you may have it to-day for aught I know) — when you had an American card made with the mechanical precision with which the English cards are now being made, you would then be able to test one system against the other.

We appear to have begun at the wrong end in this country. We appear, so far as an observer can make it out, to have perfected the looms first; and the export of looms for many years by Knowles, Crompton and others would indicate that we were ahead on looms. We then perfected the spinning frame, and we taught them in England how to build a ring spinning frame. It happens, with respect to mules, the most skilful and able mechanics have worked on both sides of the water; and whether England is ahead, or whether the United States is ahead, in the mechanical construction of mules, is an open question upon which I shall not venture to pass. Now, when you first got the Wellman card, you apparently had a

card which was better, in its day, than any of the revolving cards of England, in its day; and it had its day in England as well as here. Thereafter, and about the time I first visited England, the revolving top-flat card was beginning to come to its mechanical perfection. Since then great strides have been made, and you are now getting an idea of the competition of one country with the other, in the mechanical perfection of the carding engine.

Now, this is all subsequent to the picking. Reference has been made to that, and inasmuch as you have begun with the loom, and are now getting down as far as the card, you had better end off with the picking. [Applause.] It would have been better to have begun with the gin and the picker, and to have followed up with the loom, if it had been possible; but we didn't do it. Now, I have said to you every time I have come here that your picking department, as compared to English picking, is deficient in the exactness of the sorting of the cotton, and in the working of it. You work it twice as much as the modern English system does. I do not say which makes the best picker; I do not make any comparisons between the English picker and the American picker as a piece of mechanism, but I do say this, that you need more space in your picking department. As the change from the present system of carding to this style of card is made, you will have room left vacant in your present carding rooms, and there is no more danger in putting a finisher picker in the carding room than there is in having a carding engine there. The danger with the picker is mainly in the opening machines; therefore, the underwriters would probably raise no objection if the vacant space left by the removal of the American cards and the substitution of the English cards were filled up in the mill with finisher pickers. That will enable you even in your present picking rooms to get more room for your work. Better have ample room in the picker building.

I would say that, from my observation (having no practical knowledge), the English mills, in my opinion, are as far in

advance in the application of science to the picking as they have been in the application of science to the construction of the carding engine. I would suggest that opening and picking be the next subject; and that you get up a discussion among the English and American builders of picking machines, to develop the art. [Applause.]

Mr. E. S. DAVIS. One important thing has been omitted: the Board of Government will need funds to carry them through the year, and I move that they be authorized to assess each member not exceeding ten dollars to defray the expenses for the ensuing year. I think we can afford to pay a pretty liberal assessment this year. We have had fun enough to-day to warrant it. Adopted.

A MEMBER. I move that the thanks of the Association be extended to Mr. Draper, Mr. Dobson and Mr. Ashworth for the excellent papers that have been read to-day. Adopted.

A MEMBER. I would also move that these papers be embodied in the report to be published.

The PRESIDENT. That will be done.

Mr. THOMAS. I move the thanks of the Association be tendered to the retiring officers for their fidelity to their trust in the months past. Adopted.

The PRESIDENT. There is one more paper. Mr. JAMES R. MAXWELL of Tuscaloosa, Ala., will explain the new system of packing cotton in small bales for shipment to spinners.

New System of Packing Cotton in Small Bales for Shipment.

By James R. Maxwell, Tuscaloosa, Ala.

I beg leave to state, in the first place, that, unfortunately, my hearing is quite deficient, and it will be impossible for me to catch questions asked from the body of the house.

You have listened patiently to the addresses of the gentlemen preceding me, who were trying to show up to you a fractional part of a per cent. saving in the handling of the staple, to even test which would involve the outlay of much time and thousands of dollars in money. Each one of them has occupied your attention from an hour to an hour and a half in the presentation of his views, but I propose to take only fifteen minutes of your time, and, in that time, demonstrate to you the practicability of your saving from four to six per cent. of the staple that you pay for, and at absolutely no outlay or risk in testing the matter. You may say that there is risk in dealing with a stranger. But with the references as to character that I am enabled to give, and the guarantees I shall make, I assert that you will not *risk* a dollar. Now, to our subject.

Visiting the Cotton Exposition at Atlanta in 1881, being a cotton planter, I was much impressed with the advantages that would accrue to the spinner could he supply himself with cotton packed in blocks of about 125-pounds weight, tied with light galvanized wire ties and covered with light burlap sacking. The difference in tare was very obvious, reducing same from an average of 20 to 27 pounds down to about 8 to 10 pounds per bale of 500-pounds weight,—a palpable gain to the spinner of from 12 to 17 pounds of cotton even were both items counted as entire loss. But the difference in value of the two kinds of wrapping when stripped from the cotton was equally as marked.

This impression was made the more lasting by the testimony

there given by New England spinners as to the value of cotton so packed; its value being increased according to their judgment fully three-fourths of a cent per pound.

Mr. Atkinson expressed to the manufacturers of the press so packing the staple as follows: —

My conviction was, that your method of compressing was superior to the ordinary method, and less likely to do harm, if compression does any harm, while the cotton was cleaner, and in better condition otherwise, than if it had been packed in the ordinary manner. A small bale speaks for itself, and gives its own instructions that it shall be kept out of the mud and rain, and properly cared for.

Just here let me say that experience has proved that he was right in that. In their care and transportation they are invariably kept under *lock and key*, which necessarily involves *shelter*. They are easier to handle on the shoulder than to roll; that keeps them out of the mud. Purchasing back from the mills the sacks and wires, they come to me clean; seeing them stored in the warehouse at the mills, I find them as clean as when they left the ginneries.

In another letter Mr. Atkinson says: —

I think there will be no difficulty in finding customers for this cotton when offered by responsible growers, who can be depended upon for uniformity in the quality of the bale itself; and that very soon your bales will have the preference over the ordinary compressed bale.

The press manufacturers, Messrs. Dederick & Co. of Albany, N. Y., after the closing of the Atlanta Exposition, divided the cotton so packed into small lots and shipped to different spinners for test as to practical working up.

The Cutter Manufacturing Company of Warren, R. I., reported: —

We find them very convenient to handle, costs less to put in store house and move to mill; also less waste in transportation, and much handier to put into the packer-house. The cotton works equally as well as the large bales, and we should always prefer the small bales.

The Greenwoods Company, New Hartford, Ct., reported :—

The small bales of cotton you sent us we have carefully worked, and, *contrary to our expectations*, we are much pleased. We anticipated, in fact, firmly believed, that the process through which you put the cotton would injure the fibre, and consequently worked the cotton very carefully in the different departments of our mill. The cotton worked as well as ordinary cotton through the different processes of carding, spinning, etc. From what experience we have at present we should decidedly favor the purchase of cotton in small bales. We did not go into the matter of tare, as it seemed to us very evident that it would be less than on the large bales. We could, as a whole, handle the season's work at a much less expense in the small bales than in the large ones. The convenience of the small bales in handling and working in every way is great.

The Williamantic Linen Company, testing "Sea Island" so packed, reported : —

We made a careful examination of the cotton in the different stages of its manufacture to see to what extent it was injured by compression. We find that not only is it not injured, but it is a positive gain to us, from the fact that cotton so compressed makes less waste at the picker, in the cards and in the combing machine. You are at perfect liberty to refer to me or to the experience of this company.

Bearing on another possible advantage, *i.e.*, the question of insurance, Mr. Thos. Peters of Atlanta, Ga., general adjuster and special agent of the Underwriters' Association of the South, in a report says in 1882 : —

It will be generally conceded that, when once cotton is well afire, the destruction is limited only by the number of bales in reach ; . . . our proposition, therefore, is, that in order to decrease the amount of loss we must increase the possibility of removal of exposed bales, and at the same time, by reducing the value of the individual bale, we again curtail the loss. This necessitates a bale more easily handled than the present standard American bale, and suggests the bale of about 125 pounds as the proper type. If the present bale is worth $50, — and it is admitted that, once the bale is afire, the loss

is total, — it stands to reason that if the bale is reduced to one-fourth, say to $12.50 in value, we gain a salvage of three-fourths, and we hold this is not an unfair deduction, for as facility of removal is increased by reduction of bulk, it is by no means probable that we will lose four bales where we now lose one.

To my mind all these statements, looking at the matter from the standpoint of the spinner, were incontrovertible facts. I had then to look at the matter from my own standpoint — that of a planter. The best business men among the planters consider the difference between what they pay for bagging and iron ties as such, and the price they get for same when weighed and sold as cotton, as their own legitimate profit; and it is this class that invariably put on the heaviest bagging and the most of it allowable. The planter may be careful to free his cotton from dirt and sand by every means in his power, so that it may show a good sample, but he wants all he can make in the bagging and ties; and so acts. And he is right in that; for although it is a fact that the world, in fixing the price of the staple, counts the average loss to be expected in the tare, that does not affect his transaction. He knows that he puts on about twenty-eight pounds of bagging and ties at a cost of about 87½ cents, and sells same on the spot at say 9 cents per pound; making a certain profit in the transaction of $1.64½ per bale.

What you get with lighter tare is put up invariably by one of two distinct classes. One class, the men who, too ignorant to figure on it, invariably buy the cheapest bagging per yard and cheapest ties per set, as if it were so much money thrown away; and the other, the public ginners, who, competing with others, contract with the owner of the cotton to gin and pack and wrap it up for so much per bale.

Here was a stumbling-block, and this item thrusts itself in the way, in every case, at every shipping point I establish. The farmer must see that profit comes back to him — and more besides that — as an inducement for him to change his ways.

I suppose that it was some such consideration as this,

among others, that caused Mr. Atkinson to decide not to take the risk; for in a letter to me in 1883, I think, he used this expression, as nearly as my memory serves me: —

> While I believe the method is the proper one, and will eventually prevail, yet in a *model ginnery* that I helped to establish in Georgia I did not dare to make so radical a change.

This information was rather discouraging, but so thoroughly was I convinced of its advantages to the spinner that I determined to go ahead and prepare for the business; counting on my ability to find those who would test the matter, and being satisfied in my own mind that, when tested, sufficient saving would be found, which, fairly divided, would be mutually satisfactory.

I clean my cotton, before ginning, of sand and dust; then when placed on the feeder of gin it is not touched by hand till it issues from the press with the wire ties around the cotton itself. The lint issues from the condenser of gin, just as it does from the end of your pickers, in a continuous sheet; but, instead of being rolled in a roll, the bat falls into chamber of press, whose piston moves back and forth like that of a steam engine; at each stroke forcing the cotton into the bale chamber, section by section. Issuing from end of press already tied, its sack is slipped over it, sewed up, weighed, tagged and stored ready for shipment.

The crop of 1883 was a disastrous one in my section. From the same number of acres that had been giving me an average yield of 185 bales of 500 pounds each, I only obtained 68 bales; a shortage of about two-thirds; an unprecedented shortage then, and one never since experienced. My cotton crop that year netted me a loss of over $4,000.

I sold most of the crop that season to our local mill, at an advance over market rates, and shipped twenty-two blocks to be thoroughly tested. In consequence, the mill that made the test has purchased my whole output ever since, — a conclusive proof that the profit in handling it has been satisfactory and of mutual satisfaction as to fair dealing between the contracting parties.

How much saving the spinner finds in it exactly it is not my business to know. Suffice it to say that my guarantee, given at the commencement of the business and standing to-day, viz., "That whenever he will say that his year's purchases of me have not saved him at least one-fourth of a cent per pound over cotton bought the old way, I would make the deficit good," has never been called upon.

To give you an idea as to the increase of this business, I call your attention to the following shipments of the different years: —

In season of 83–84, 22 blocks.
" " " 84–85, 758 blocks.
" " " 85–86, 5,415 blocks.
" " " 86–87, 3,826 blocks.
" " " 87–88, 13,735 blocks, counting a few I have on hand still.

Now, gentlemen, this shows that I have brought the business out of the domain of risky venture into practical working order. It is impossible that one of you who knows him can doubt that the spinner has found a saving that has been worth his while. Where improvements in the handling were needed he has promptly pointed them out, and I have, as quickly as possible, met his suggestions. The business has been carried on to our mutual satisfaction. I can truly say that if, in extending the business beyond his needs, I shall always find myself dealing with gentlemen of the same calibre, I shall be fortunate indeed. What he thinks of me can best be attested to those interested, over his own signature. While in comfortable circumstances, I am not a very wealthy man; but for business integrity I am proud to be able to point to a record as merchant, as planter and as cotton dealer, without a flaw. My credentials will bear the closest scrutiny or any amount of private inquiry.

My object in presenting this business before this Association is easily explained. Here I meet, in one body, gentlemen whose object in coming is to keep an open eye and ear for every possible improvement or saving in connection with their

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(No. 45.)

N. E. COTTON MANUFACTURERS' ASSOCIATION.

PROCEEDINGS

OF THE

SEMI-ANNUAL MEETING,

HELD AT BOSTON,

OCTOBER 31, 1888.

BOSTON:
WRIGHT & POTTER PRINTING CO.,
18 POST OFFICE SQUARE.
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CALL FOR MEETING.

BOSTON, Oct. 1, 1888.

DEAR SIR: — The stated Semi-annual Meeting of the Association will be held at the Massachusetts Institute of Technology, Boylston Street, Boston, on Wednesday, Oct 31, 1888, at 10 o'clock A.M.

Topics heretofore discussed will still be in order if called up by any member; and, in addition, the Board have the pleasure to announce the following: —

A committee appointed by the Board of Government to investigate the subject of PICKING, will present a report, with accompanying tables.

Mr. SCOTT A. SMITH, of Providence, R. I., will read a paper on the subject of LEATHER BELTS, and the mode of determining the comparative value of different makes.

Mr. GEORGE A. BARRUS, of Boston, Mass., will present a paper upon STEAM BOILER TESTS, with tabulated results of 150 evaporative tests conducted by him.

These papers will be printed in advance of the meeting, and a copy of either supplied to any member who applies for it to the Secretary.

By vote of the Board of Government,

AMBROSE EASTMAN,

Secretary.

PROCEEDINGS.

Pursuant to the foregoing notice the stated semi-annual meeting of the Association was held at the Massachusetts Institute of Technology on Wednesday, Oct. 31, 1888. President LIPPITT in the chair.

The PRESIDENT. The first business before the meeting is to consider nominations for membership. We have the following list, which the Board of Government has by vote recommended for election.

Messrs.	GEORGE ASHWORTH,	Manchester, Eng.
	EBEN S. DRAPER,	Hopedale, Mass.
	GEORGE A. DRAPER,	Hopedale, Mass.
	JOHN F. HAMLET,	Manville, R. I.
	GEORGE E. KENT,	Pittsfield, N. H.
	JOHN M. KIMBALL,	Lewiston, Me.
	J. H. A. KLAUDER,	Philadelphia, Penn.
	WEBSTER KNIGHT,	Providence, R. I.
	WILLIAM S. SOUTHWORTH,	Lowell, Mass.
	CHARLES F. TARBELL,	Woonsocket, R. I.
	ARIEL C. THOMAS,	Woonsocket, R. I.
	JOHN WALTER WELLS,	Atlantic City, N. J.
	A. S. WINSLOW,	Crompton, R. I.

By vote of the Association the above-named gentlemen were duly elected members.

The PRESIDENT. The first subject which has been proposed for discussion at this meeting is the report of a committee appointed by the Board of Government to investigate the sub-

ject of PICKING. I will say that the committee selected Mr. FREDERICK G. REED to conduct that investigation, which he did, and the report of his work will now be presented. Since completing it, I regret to announce, Mr. Reed has deceased; and Mr. PARKER of the Pacific Mills, a member of the committee appointed by the Board of Government, has consented to present the subject to your attention.

Mr. WALTER E. PARKER. Mr. President, about one year ago a committee was appointed, at the suggestion of President SUDLAM, to investigate picking among some of the mills in New England. The work was outlined by the committee, and Mr. FREDERICK G. REED was selected to carry out the investigation, and copies of his report have been distributed in the hall, for the members to look over. I will read simply the subject-matter of the report. The opinions expressed in this paper are Mr. Reed's, and were probably formulated during his investigation of picking. He was a young man very careful in his methods, and one whom we thought fully competent to investigate such a subject.

INVESTIGATION OF PICKERS

MADE BY

FREDERICK G. REED,

UNDER THE DIRECTION OF A COMMITTEE OF THE BOARD OF GOVERNMENT.

The different combinations of pickers met with in twenty representative mills are very numerous. Among openers the stick or willow whippers and the Crighton opener are still retained in some instances. Of the English lappers in use here there are the Lord, the Walker and Hacking, the Hetherington, the Platt, the Leigh, and the Taylor and Lang; all of which have been running in most cases a long time, and many of which have been made over or combined with lappers made here.

While the makers of pickers in this country have been numerous, they are built in general after the pattern of the Lord or the Walker and Hacking machine. There are at present three distinctive types of openers made here: the porcupine preparer, the whipper beater, and the Buckley opener; the last of which is properly an English machine and of recent appearance here.

To obtain more even work the tendency at present is to increase the number of processes by substituting a greater number of single-section machines for a less number of machines of several sections each.

The subject of decreasing the number of beaters has been discussed for a long time, but only lately has it been put in practice to any considerable extent. It seems to have been admitted long ago that it was customary by too high a speed

and by too heavy and too many beaters to over-pound cotton before it went to the cards.

The decrease in the number of beaters is undoubtedly an advantage, as is also the increase in the number of doublings.

The English improvement in this direction has been toward the steady reduction in the number of beaters, and the establishment of a rate of speed at 1,000 to 1,300 revolutions of a sixteen-inch beater; the average number of beaters in the entire operation of opening and picking being three or four, the average number here being five or six.

The present investigation was made solely to ascertain as nearly as possible what was actually being done in a number of representative mills. While there may be some points of no especial interest, and some points omitted that would be of greater value, yet so far as it goes the aim has been to be as thorough and accurate as circumstances would permit.

It would be impossible to obtain results which would be entirely infallible, especially in regard to per cent. of waste, weight of laps and product, as in no two cases would the circumstances be precisely the same; but similar methods were pursued in each case, and sufficient details are given in most cases to account for any discrepancy.

There are included in the report twenty mills, which are designated by the numbers in the extreme left-hand column on each page. Where the picking for an entire corporation was done in one picker building, the figures for the whole are given; but in cases where the picking for each mill was done separately, a single representative picker-room was selected, and its description and operations alone given.

The first thirteen mills are entirely or chiefly equipped with the Kitson system; the remaining seven with the Whitehead and Atherton system, either entirely or for the most part. The mills under either system are arranged according to the grade of stock found in use, beginning with those using the highest grade.

The porcupine beater in the preparer was found making from 390 to 920 revolutions per minute, delivering from 780 to

1,840 blows; the flexible whipper beater was found making from 1,060 to 1,345 revolutions, delivering from 3,180 to 4,035 blows per minute.

In regard to the distance at which the beaters in the openers are set from the feed-rolls, with the whipper beater the average distance is one-half inch from the circumference of feed-rolls and the diameter of feed-roll is two and one-half inches, or an average distance of one and three-quarters inches from bite of feed-rolls to blade of beater. With the preparer the average distance is three-eighths of an inch from circumference of feed-rolls and the diameter of feed-roll is three inches, or an average distance of one and seven-eighths inches from bite of feed-rolls to circumference of beater.

The average per cent. of waste taken out by the preparer is about one-third of one per cent.; that taken out by the whipper beater about two-thirds of one per cent., or about twice as much as by the preparer. The preparer and the whipper beater are each referred to in the table under openers, as the first beater.

Concerning the hollow or solid shaft beater opinion is about equally divided; at one mill where both were in use throughout an entire process, the following results were obtained from a test with each, using cotton in both cases of the same grade out of the same lot: —

	Solid shaft.	Hollow shaft.
	Per cent.	Per cent.
Preparer,	.32	.42
Breaker, first beater,	.16	.21
Breaker, second beater,	.21	.31
Finisher, first beater,	.11	.13
Finisher, second beater,	.11	.13
Hoops,	2.10	1.80
Sacks,	2.84	3.27
Trunk,	.73	.63
Unaccounted for,	1.05	.69
Finisher laps,	92.37	92.41
	100.00	100.00

While the per cent. of waste taken out from under the hollow-shaft beaters was greater than that taken out from under the solid-shaft beaters, yet this excess was offset by the less amount of waste from the trunk and that unaccounted for.

A large variation was found in the speed at which beaters were running, the lowest being 1,050 and the highest being 1,710 revolutions per minute. The least number of blows delivered by a beater under breaker pickers is 2,620 per minute, the greatest number is 4,480; the least number under finisher pickers is 2,500 and the greatest is 4,260. The average number of blows delivered by a beater under breaker pickers is 2,996, under finisher pickers, 2,957; and the average number for all beaters is 2,979. The least number of blows delivered per minute in any one entire process from opener to finisher is 9,240 and the greatest number is 20,820, the average number for the twenty mills being 16,618; the least number occurring in a mill where there were three processes, a breaker, an intermediate and a finisher of one beater each, or a total of three beaters and a preparer; the greatest number occurring in a mill using a preparer and beater attached by a cleaning trunk to a breaker picker of three beaters, and using a finisher picker of two beaters, or a total of six beaters and a preparer. This variation in the speed of beaters, as well as the variation in the speed of feed-rolls, and in the distance at which beaters are set from feed-rolls, does not seem to depend with any regularity upon the requirements of the stock used. In too many cases these things remain the same year after year, and the same amount of cotton is pushed through the pickers without regard to any difference in the length or character of staple.

As a rule, beaters are set nearer to the feed-rolls the farther they are removed from the opening process; the average distance for first beater after the opener being one-third of an inch, and for the last beater in the finisher less than three-sixteenths; the average distance for all beaters being $\frac{7}{32}$ of an inch, and the diameter of feed-rolls two inches; giving an

average distance from bite of feed-rolls to blade of beater of $1\frac{7}{32}$ inches.

Advancing from opener to finisher the amount of waste taken out by each beater diminishes; but quality as well as quantity is important in this consideration, for there is much good fibre often taken out in picking which might be kept with advantage in the work; the best picker in this respect being that which removed the greatest amount of foreign matter and the least amount of fibre, and did the least injury to the staple, leaving the removal of all unsuitable fibre for the card.

The lightest lap found on a breaker picker weighed 9.4 ounces per yard, the heaviest 20.43 ounces, the average weight of the breaker lap being 13.97 ounces per yard. The smallest production on a breaker picker was found to be 3.5 yards of lap per minute, giving a theoretical product for ten hours of 2,062 pounds; the largest production 11.66 yards per minute, or 6,562 pounds for ten hours; the average being 7.66 yards of lap per minute, or a theoretical product of 4,015 pounds for ten hours.

The lightest lap found on a finisher picker weighed 8.35 ounces per yard, the heaviest 13.8 ounces; the average weight of the finisher lap being 10.92 ounces per yard. The smallest production on a finisher picker was found to be 2.5 yards of lap per minute, giving a theoretical production for ten hours of 1,294 pounds; the largest production, 8.67 yards per minute, or 3,391 pounds for ten hours; the average being 5.28 yards of lap per minute, and a theoretical production of 2,131 pounds for ten hours.

The smallest actual production of a breaker picker, estimated in yarn, was found to be 1,276 pounds for ten hours, the largest 3,269 pounds, and an average of 2,357 pounds for ten hours. The smallest actual production of a finisher picker, estimated in yarn, was found to be 722 pounds for ten hours, the largest 1,899 pounds, and an average of 1,363 pounds for ten hours.

A great difference was found in the length of time during which pickers are actually in operation, in some cases not

averaging more than two-thirds of the running time of the mill. This amount of stoppage is not necessary, surely, for cleaning purposes, and if partly utilized would allow lighter and more thorough picking. A great disadvantage in most picker-rooms is in crowding through more work than the pickers can properly take care of, to sacrifice quality to quantity of work.

Manufacturers of lappers urgently call attention to this matter, and in those mills where new pickers have recently been put in a much less amount of cotton is put through a machine than is the case in many mills where the pickers have been run for a long period of years. Especially since the introduction of English cards has the necessity been felt for more thorough picking, and the advantages of it in the subsequent processes more than make up for any additional cost.

In the per cent. of loss in picking there is, of course, a large variation, owing to the difference in grades of stock used. The total loss from bale to finisher laps averaged 9.32 per cent.; the smallest total loss was 6.24 per cent., the largest 16.42 per cent., the difference being over 10 per cent. The average per cent. of tare in hoops and sacks was 4.25 per cent.; the average loss in waste 5.07 per cent. The practice in mills of testing each lot of cotton used to ascertain amount of loss in picking is not as general as would seem advisable; for example, in two lots of cotton with a difference of seven-eighths of a cent in price, the actual difference as found by working them was as great as three cents.

The lowest cost of picking found was .058 cents per pound, the highest .137 cents, the average cost being .094 cents per pound; this difference is due, of course, to a variety of causes, but an examination of all the details enumerated will, in most every case, afford an explanation.

The importance of the trunk as a means of cleaning cotton is now generally acknowledged, particularly in cleaning low grades of stock. The arrangement of a trunk system where the opener trunks down to the picker, or where both are on the same floor, is preferable to the system of trunking up from below; for a much less current of air is required, thereby

allowing the cotton to be drawn along more gently over the grid-bars of the trunk and to become more thoroughly opened, and allowing the sand to fall out more readily. The length of trunk given in each case is the length of actual cleaning trunk in which grates are placed.

The smallest dust-room capacity found was 225 cubic feet per fan, the largest capacity 2,186 cubic feet, the average being 1,045 cubic feet per fan. The smallest area of dust-chimney or outlet found was 115 square inches per fan, the largest $7\frac{7}{10}$ square feet, the average being $3\frac{1}{4}$ square feet per fan. The average dust-room capacity per fan is considerably below that usually recommended, which is 1,700 cubic feet per fan; the average area of dust-chimney or outlet is fully up to that usually recommended, which is 3 square feet per fan.

I would strongly recommend the removal of all screens and nettings from dust-rooms, so that the outlet may be perfectly open and free at all times. With the capacity of dust-room and the area of outlet as recommended, and dust-flues with an area of 216 square inches per fan, the currents of air will be sufficiently light so that no waste cotton will be carried away. This has much to do also in regard to the splitting of laps, a very common source of trouble, which may be avoided almost always by a proper regulation of the fan-drafts.

Another matter to which attention might well be directed is the advisability of large mixings; for in the majority of picker-rooms there is not sufficient space for opening more than a very limited supply, so that cotton is often fed to the pickers directly from the bale.

It is here, and in more thorough, but not excessive, picking that improvement may be made.

PREPARATION.

By whom Cotton is Opened.	Where Mixed.	Number Bales per Opening.	How long Opened before Used.	Consumption per Week.	Air Warmed besides Circulation.
Spare hands, . .	In bins, ...	35	Not over ½ day, .	420	Air drawn from carding and spinning rooms.
Picker hands and card strippers.	On floor of picker-room,	50	From 1 to 3 days,	100	– –
Yard hands, . .	In bin, ...	60	From 1 to 10 days,	36	Air drawn from card-room.
Yard hands and picker hands.	In bins, ...	60	Not over 2 days, .	180	Air drawn from carding and spinning rooms.
Picker hands and card strippers.	In bins, ...	250	From 1 to 6 days,	250	Air drawn from basement of mill.
Spare hands, . .	On floor of picker-room,	60	Not over 1 day, .	360	Air drawn from card-rooms and boiler house.
Spare hands, . .	On floor of picker-room,	11	Not over ¼ day, .	260	Air drawn from basement of mill.
Yard hands and picker hands.	On floor of picker-room,	40	From 1 to 14 days,	20	Air drawn from card-room.
Picker hands, . .	In bins, ...	120	From 1 to 3 days,	240	– –
Picker hands, . .	In bins, ...	45	Not over 1 day, .	225	Air drawn from card-room.
Spare hands, . .	On floor of picker-room,	125	Not over 2 days, .	375	Air drawn from basement of mill.
Spare hands, . .	In bins, ...	–	Used as soon as opened.	450	Air drawn from carding and spinning rooms.
Spare hands, . .	In bins, ...	60	Not over 1 day, .	300	– –
Yard hands, . . .	On floor of picker-room,	143	From 1 to 6 days,	143	– –
Spare hands, . .	On floor of picker-room,	42	Not over ½ day, .	500	Air drawn from card-rooms.
Yard hands and card strippers.	On floor of picker-room,	100	From 1 to 3 days,	200	Air drawn from card-room.
Spare hands, . .	On floor of picker-room,	100	From 1 to 3 days,	200	Air drawn from card-room.
Spare hands, . .	In bins, ...	133	Not over 2 days, .	400	Air drawn from basement of mill.
Spare hands, . .	On floor of picker-room,	47	Not over 1½ days,	188	Air drawn from card-room and engine-room.
Yard hands, . .	In bin, ...	25	From 1 to 4 days,	37	– –

OPENERS.

Mill.	Number.	Maker.	Pattern.	Beaters. Number.	Hollow or Solid.	Speed.	Blows per Minute.	Total Blows per Minute.	Dist. from Feed-roll.	Diameter Feed-roll.	Per cent. Waste.	Total per cent. Waste.
1	10	Kitson, .	Preparer, . .	1st	S	695	1,390	1,390	⅜"	3"	.11	.11
2	4	Kitson, .	Preparer, . .	1st	S	920	1,840	1,840	½"	2½"	.35	.35
3	2	Kitson, .	Preparer, . .	1st	S	560	1,120		⅜"	3"	.57	
				2d	H	1,260	2,520	3,640	5-16"	2½"	.43	1.00
4	4	Kitson, .	Preparer, . .	1st	S	410	820		½"	3"	.18	
				2d	H	1,225	3,675	4,495	¼"	2⅜"	.46	.64
5	6	Kitson, .	Preparer, . .	1st	S	610	–	–	¼"	3"	.10	.10
6	10	Kitson, .	Preparer, . .	1st	S	390	780		¼"	3"	.17	
				2d	H	1,180	3,540	4,320	½"	2½"	.28	.45
7	8	Kitson, .	Preparer, . .	1st	S	810	1,620	1,620	½"	3"	.40	.40
8	1	Kitson, .	Lord, . .	1st	H	1,125	3,375	3,375	⅜"	2½"	.16	.16
9	5	Kitson, .	Preparer, . .	1st	S	750	1,500		½"	3"	.12	
				2d	S	1,100	4,400	5,900	⅜"	2"	.25	.37
10	9	Kitson, .	Preparer, . .	1st	S	808	1,616		½"	3"	.36	
				2d	H	1,195	3,585	5,201	⅜"	2⅞"	.82	1.18
11	6	– .	Stick Whipper,	–	–	–	–	250	–	–	–	.29
12	12	Kitson, .	Preparer, . .	1st	S	875	1,750	1,750	7-16"	2½"	.29	.29
13	9	Kitson, .	Preparer, . .	1st	S	790	1,580	1,580	5-16"	2⅞"	1.27	1.27
14	6	1 Kitson, .	Preparer, . .	1st	H							
		5 W. & A., .	Whipper, . .	1st	S	1,340	4,020	4,020	½"	2½"	.50	.50
15	12	1 Kitson, .	Preparer.									
		11 W. & A., .	Whipper, . .	1st	S	1,345	4,035	4,035	⅜"	2½"	.41	.41
16	5	Atherton, .	Whipper, . .	1st	S	1,295	3,885	3,885	¼"	2½"	.40	.40
17	5	Atherton, .	Whipper, . .	1st	H	1,150	3,450	3,450	7-16"	2½"	1.00	1.00
18	8	W. & A., .	Whipper, . .	1st	S	1,230	3,690	3,690	½"	2½"	.32	.32
19	5	W. & A., .	Whipper, . .	1st	S	1,190	3,570		11-16"	2¼"	.73	
				2d	S	1,540	3,080	6,650	3-16"	2"	.66	1.39
20	2	W. & A., .	Whipper, . .	1st	S	1,060	3,180	3,180	9-16"	2½"	.85	.85

BREAKERS.

Mill.	Number.	Maker.	Pattern.	Eveners.	System of Trunks.	Length of Trunk.	Weight of Lap per Yard.	Yards of Lap per Minute.	Theoretical Product 10 Hours.	Average Actual Product 10 Hours.
							oz.		lbs.	lbs.
1	10	Kitson, . .	Lord, .	-	- -	-	15.75	8.92	5,268	2,854
2	4	Whitin, . .	Lord, .	-	- -	-	13.00	5.10	2,486	1,586
3	3	1 Kitson, . .	Lord, .	C. & P.,	- -	-	15.71	3.50	2,062	1,444
		2 T. L. & Co., .	W. & H.,	Lord, .						
4	4	Kitson, . .	Lord, .	C. & P.,	Openers trunk backward to breakers.	40'	20.43	7.89	6,045	2,822
5	6	Kitson, . .	Lord, .	-	- -	-	15.83	7.83	4,648	2,583
6	10	Kitson, . .	Lord, .	C. & P.,	Openers trunk backward and up to breakers.	50'	17.00	9.90	6,311	3,269
7	8	Kitson, . .	Lord, .	-	- -	-	16.90	7.78	4,931	2,625
8	1	Kitson, . .	Lord, .	-	Opener trunks backward and down to breaker.	48'	13.97	4.58	2,400	1,276
9	5	Kitson, . .	W. & H.,	C. & P.,	Openers trunk backward and up to breakers.	48'	14.66	6.55	3,602	2,425
10	9	2 Kitson, . .	Lord, .	-	Openers trunk backward and down to breakers.	50'	12.33	7.50	3,469	2,532
		2 W. & A., .	W. & H.,							
		5 Hetherington,	W. & H.,							
11	14	8 Kitson, . .	Duplex, .	-	- -	-	16.70	6.16	3,858	2,185
		6 Lord, . .	Lord, .							
12	12	6 Kitson, . .	Lord, .	-	- -	-	11.00	9.82	4,051	2,533
		5 Lord, . .	Lord, .							
		1 W. & H., .	W. & H.,							
13	9	Kitson, .	8 Lord, .	C.& P.,	- -	-	13.62	10.74	5,485	2,279
			1 W. & H.,							
14	6	2 Kitson, .	W. & H.,	-	Openers trunk backward to breakers.	45'	11.43	7.00	3,000	1,532
		4 W. & A.,								
15	12	1 Kitson, .	W. & H.,	-	Openers trunk forward up and down to breakers.	50'	-	-	-	-
		11 W. & A.,				40'	14.00	7.51	3,943	2,917
16	6	2 Kitson, . .	Lord, .	-	Openers trunk backward and up to breakers.	50'	10.80	8.33	3,375	2,733
		4 W. & A., .	W. & H.,							
17	5	Atherton, .	W. & H.,	-	Openers trunk backward to breakers.	50'	10.44	7.66	3,000	1,781
18	8	W. & A.,	5 Lord, .	-	Openers trunk forward to breakers.	20'	15.00	11.66	6,562	3,147
			3 W. & H.,							
19	5	W. & A., .	W. & H.,	-	Openers trunk backward and up to breakers.	46'	11.51	7.17	3,095	2,523
20	2	W. & A., .	W. & H.,	-	- -	-	9.40	7.66	2,700	2,094

[The last column represents the actual product of the mill in cloth or yarn, divided by the number of breakers.]

BREAKERS.

Mill.	Number.	Hollow or Solid.	Speed.	Blows per Minute.	Total Blows per Minute.	Dist. from Feed-roll.	Diameter of Feed-roll.	Per cent. Waste.	Total per cent. Waste.	Length of Dust-pipes.	Trunk Waste per ℔ Cotton.	Per cent. Trunk Waste.
				BEATERS.								
1*	1st	Solid, .	1,210	3,630		¼"	2½"	.44				
	2d	Solid, .	1,490	2,980		⅛"	2½"	.33				
	3d	Solid, .	1,490	2,980	9,590	⅞"	2½"		.77	–	–	–
2	1st	Solid, .	1,670	3,340		⅛"	2"	.25				
	2d	Solid, .	1,665	3,330		⅛"	2"	.20				
	3d	Solid, .	1,665	3,330	10,000	⅛"	2¼	.20	.65	–	–	–
3†	1st	Hollow,	1,500	3,000	3,000	3-16"	2"	.42	.42	–	–	–
4	1st	Hollow,	1,445	2,890		¼"	2"	.38				
	2d	Hollow,	1,445	2,890		3-16"	2"	.37				
	3d	Hollow,	1,445	2,890	8,670	3-16"	2"	.33	1.08	–	.011	20
5	1st	Hollow,	1,500	3,000		9-16"	2½"	.32				
	2d	Hollow,	1,500	3,000		3-16"	2"	.27				
	3d	Solid, .	1,540	–	6,000	¼"	2"	.10	.69	30'	–	–
6	1st	Hollow,	1,180	3,540		3-16"	2"	.28				
	2d	Hollow,	1,180	3,540		3-16"	2"	.24				
	3d	Hollow,	1,180	3,540	10,620	¼"	2"	.17	.69	15' to 90'	.013	25
7	1st	Hollow,	1,050	3,150		⅜"	2½"	.71				
	2d	Hollow,	1,600	3,200		3-16"	2"	.46				
	3d	Hollow,	1,600	3,200	9,550	3-16"	2"	.36	1.53	–	–	–
8	1st	Hollow,	1,330	2,660		3-16"	2½"	.45				
	2d	Hollow,	1,330	2,660	5,320	⅛"	2"	.47	.92	–	.0101	21
9	1st	Solid, .	1,410	2,820		¼"	2"	.21				
	2d	Solid, .	1,405	2,810	5,630	3-16"	2"	.21	.42	32'	.0074	27
10	1st	Solid, .	1,485	2,970		¼"	2⅞"	.51				
	2d	Solid, .	1,485	2,970		3-16"	2 1-16"	.31				
	3d	Solid, .	1,485	2,970	8,910	3-16"	2"	.26	1.08	–	.014	32
11	1st	Solid, .	1,310	2,620		⅜"	3"	.94				
	2d	Solid, .	1,555	3,110		¾"	2"	.49				
	3d	Solid, .	1,535	3,070	8,800	5-16"	2"	.35	1.78	42' to 63'	–	–
12	1st	Solid, .	1,435	2,870		5-16"	2¼"	1.26				
	2d	Solid, .	1,410	2,820		5-16"	2"	.73				
	3d	Solid, .	1,395	2,790	8,480	5-16"	2"	.53	2.52	20' to 50'	–	–
13	1st	Solid, .	1,430	2,860		¼"	2"	1.96				
	2d	Solid, .	1,405	2,810		3-16"	2"	1.33				
	3d	Solid, .	1,405	2,810	8,480	¼"	2"	.90	4.19	–	–	–
14	1st	Solid, .	1,360	2,720		3-16"	2"	.94				
	2d	Solid, .	1,385	2,770	5,490	⅞"	2"	.59	1.53	29'	.0075	17
15	1st	Solid, .	1,255	3,765		¼"	2"	.33				
	2d	Solid, .	1,640	3,280		⅜"	2"	.26				
	3d	Solid, .	1,565	3,130	10,175	¼"	2"	.16	.75	13'	.0071	25
16	1st	Solid, .	1,525	3,050		3-16"	2"	.71				
	2d	Solid, .	1,575	3,150	6,200	⅞"	2"	.28	.99	48' to 88'	.0175	35
17	1st	Solid, .	1,580	3,160		3-16"	2"	.66				
	2d	Solid, .	1,540	3,080	6,240	3-16"	2"	.57	1.23	24' to 37'	.0125	28
18	1st	Hollow,	1,120	4,480		¼"	2"	.80				
	2d	Hollow,	1,375	2,750	7,230	¼"	2"	1.04	1.84	–	.0068	12
19	1st	Solid, .	1,450	2,900		¼"	2"	.39				
	2d	Solid, .	1,485	2,970	5,870	¼"	2"	.58	.97	40'	.0121	18
20	1st	Solid, .	1,410	2,820		3-16"	2'	.64				
	2d	Solid, .	1,365	2,730	5,550	3-16"	2"	.43	1.07	–	–	–

* Waste test made on two beater machines. † Single beater intermediate.

FINISHERS.

Mill.	Number.	Maker.	Pattern.	Eveners.	Doublings.	Weight of Lap per Yard.	Yards of Lap per Minute.	Theoretical Product 10 Hours.	Average Actual Product 10 Hours.
						oz.		lbs.	lbs.
1	20	Kitson,	Lord,	16 Lord, 4 C. & P.,	3	10.25	6.32	2,429	1,427
2	4	W. & A.,	W. & H.,	Lord,	3	8.50	6.28	2,002	1,586
3	4	2 Kitson, 2 T. L. & Co.,	Lord, W. & H.,	C. & P., Lord,	3 4	– 11.00	– 3.50	– 1,444	– 722
4	7	Kitson,	Lord,	C. & P.,	3	17.12	4.68	3,005	1,613
5	12	Kitson,	4 Lord, 8 W. & H.,	Lord,	3	12.72	5.66	2,700	1,291
6	20	Kitson,	Lord,	4 C. & P., 16 Lord,	3	12.67	5.44	2,822	1,634
7	15	Kitson,	Lord,	2 Lord, 13 C. & P.,	4 3	– 11.90	– 5.23	– 2,334	– 1,400
8	1	Kitson,	Lord,	C. & P.,	3	11.13	5.03	2,100	1,276
9	7	2 Lord, 5 Kitson,	4 Lord, 3 W. & H.,	C. & P.,	3	8.61	6.33	2,045	1,732
10	10	9 Kitson, 1 Hetherington,	W. & H.,	Lord, C. & P.,	3	10.43	8.67	3,391	1,899
11	27	18 Kitson, 9 Lord,	W. & H., Lord,	Lord,	3	12.00	4.16	1,872	1,093
12	23	1 W. & H., 11 Lord, 11 Kitson,	1 W. & H., – 22 Lord,	7 C. & P., – 16 Lord,	3	10.00	4.91	1,841	1,321
13	18	Kitson,	2 W. & H., 16 Lord,	Lord,	3	10.34	5.46	2,117	1,140
14	8	2 W. & H., 2 Kitson, 4 W. & A.,	W. & H.,	Lord,	3	9.11	4.83	1,650	1,149
15	24	4 Lowell, 7 Kitson, 13 W. & A.,	8 Lord, – 16 W. & H.,	Lord,	3	10.00	5.01	1,879	1,458
16	9	3 Kitson, 6 W. & A.,	W. & H.,	Lord,	3	8.35	6.17	1,932	1,518
17	8	W. & H.,	W. & H.,	Lord,	3	8.55	4.33	1,388	1,113
18	17	4 Leigh, 6 Kitson, 7 W. & A.,	3 Lord, – 14 W. & H.,	Lord,	3	12.50	5.60	2,625	1,574
19	10	W. & A.,	W. & H.,	Lord,	3	9.33	5.00	1,744	1,261
20	2	W. & A.,	W. & H.,	Lord,	3	13.80	2.50	1,294	1,047

[Last column represents the actual product of the mill in cloth or yarn, divided by number of finishers.]

FINISHERS.

Beaters.

Mill.	Number.	Hollow or Solid.	Speed.	Blows per Minute.	Total Blows per Minute.	Dist. from Feed-roll.	Diameter of Feed-roll.	Per cent. Waste.	Total per cent. Waste.	Length of Dust-pipes.
1	1st	Solid, .	1,395	2,790	5,580	⅛"	2⅛"	.32	.54	40' to 50'
	2d	Solid, .	1,395	2,790		¼"	2"	.22		
2	1st	Solid, .	1,515	3,030	6,100	¼"	2"	.30	.60	12' to 40'
	2d	Solid, .	1,535	3,070		¼"	2"	.30		
3	1st	Hollow,	1,300	2,600	2,600	¼"	2"	.33	.33	-
4	1st	Hollow,	1,445	2,890	5,780	3-16"	2"	.41	.64	-
	2d	Hollow,	1,445	2,890		3-16"	2"	.23		
5	1st	Hollow,	1,500	3,000	6,000	⅛"	2"	.37	.81	30'
	2d	Hollow,	1,500	3,000		⅛"	2"	.27		
	3d	Solid, .	740	-		3-32"	2"	.17		
6	1st	Hollow,	1,470	2,940	5,880	⅛"	2"	.31	.55	15' to 40'
	2d	Hollow,	1,470	2,940		⅛"	2"	.24		
7	1st	Hollow,	1,540	3,080	6,160	3-16"	2"	.51	.82	35' to 45'
	2d	Hollow,	1,540	3,080		3-16"	2"	.31		
8	1st	Hollow,	1,350	2,700	5,400	3-16"	2"	.28	.44	-
	2d	Hollow,	1,350	2,700		⅛"	2"	.16		
9	1st	Solid, .	1,400	2,800	5,600	3-16"	2"	.11	.22	28'
	2d	Solid, .	1,400	2,800		⅛"	2"	.11		
10	1st	Solid, .	1,485	2,970	5,940	3-16"	1⅞"	.51	.82	-
	2d	Solid, .	1,485	2,970		3-16"	2¼"	.31		
11	1st	Solid, .	1,620	3,240	6,660	⅜"	2"	.30	.50	46'
	2d	Solid, .	1,710	3,420		⅛"	2"	.20		
12	1st	Solid, .	1,450	2,900	5,800	¼"	2"	.50	.79	9' to 62'
	2d	Solid, .	1,450	2,900		¼"	2"	.29		
13	1st	Solid, .	1,500	3,000	5,980	3-16"	2"	1.17	2.12	17' to 30'
	2d	Solid, .	1,490	2,980		3-16"	2"	.95		
14	1st	Solid, .	1,695	3,390	6,780	3-16"	2"	.22	.49	6' to 72'
	2d	Solid, .	1,695	3,390		⅛"	2"	.27		
15	1st	Solid, .	1,540	3,080	5,580	¼"	2"	.22	.34	13'
	2d	Solid, .	1,250	2,500		⅛"	2"	.12		
16	1st	Solid, .	1,440	2,880	5,920	3-16"	2"	.40	.66	60'
	2d	Solid, .	1,520	3,040		1/16"	2"	.26		
17	1st	Solid, .	1,420	4,260	8,529	1/32"	2"	.23	.46	27' to 32'
	2d	Solid, .	1,420	4,260		1/32"	2"	.23		
	3d	Solid, .	1,285	-		1-16"	1⅗"	-		
18	1st	Hollow,	1,610	3,220	6,440	3-16"	2"	1.38	2.42	-
	2d	Hollow,	1,610	3,220		⅛"	2"	1.04		
19	1st	Solid, .	1,480	2,960	6,000	¼"	2"	.44	.76	-
	2d	Solid, .	1,520	3,040		⅛"	2"	.32		
20	1st	Solid, .	1,395	2,790	5,570	3-16"	2"	.85	1.60	-
	2d	Solid, .	1,390	2,780		3-16"	2"	.75		

WASTE.

Mill.	Per cent. Waste Opener.	Per cent. Waste Breaker.	Per cent. Waste Finisher.	Per cent. Waste Trunk.	Per cent. Waste Tare.	Finisher Laps.	Per cent. Waste unaccounted for.	Total.	Grade of Cotton.	Cubic Feet of Dust-room.	Cubic Feet per Beater.	Square Feet of Outlet.	Square Feet per Beater.
1	.11	.77	.54	–	4.78	92.76	1.04	100	Good middling, . .	27,972	500	200	3⅕
2	.35	.65	.60	–	4.25	92.61	1.54	100	Good middling, . .	13,158	658	16	4-5
3	1.00	.42	.33	–	5.12	90.76	2.37	100	Good middling, . .	7,020	780	30	3½
4	.64	1.08	.64	1.01	4.33	90.55	1.75	100	Strict middling, . .	55,040	1,835	75	2½
5	.10	.69	.81	–	3.93	92.16	2.31	100	Middling, . . .	91,000	1,896	128	2⅔
6	.45	.69	.55	1.18	4.30	91.06	1.77	100	Middling, . . .	60,083	751	617	7 3-5
7	.40	1.53	.82	–	4.19	90.66	2.40	100	Middling, . . .	40,000	784	240	4 3-5
8	.16	.92	.44	.91	5.16	90.51	1.90	100	Middling, . . .	1,728	346	18	3 3-5
9	.37	.42	.22	.68	5.01	92.46	.84	100	Strict low middling, .	27,328	942	24	4-5
10	1.18	1.08	.82	.57	3.59	92.19	.57	100	Low middling, . .	86,958	1,553	224	4
11	.29	1.78	.50	–	3.91	90.11	3.41	100	Low middling, . .	85,075	935	140	1½
12	.29	2.52	.79	–	3.84	89.51	3.05	100	Low middling, . .	50,400	586	256	3
13	1.27	4.19	2.12	–	3.81	83.58	5.03	100	Low middling, . .	39,432	626	128	2
14	.50	1.53	.49	.69	3.81	92.19	.79	100	Good middling, . .	32,934	969	74	2 1-5
15	.41	.75	.34	.63	3.71	93.76	.40	100	Strict middling, . .	196,603	2,048	698	7¼
16	.40	.99	.66	1.61	3.57	91.80	.97	100	Strict middling, . .	7,896	225	112	3 1-5
17	1.00	1.23	.46	1.14	4.44	91.54	.19	100	Strict middling, . .	15,300	2,186	55	1½
18	.32	1.84	2.42	.61	4.94	89.18	.69	100	Strict middling, . .	64,416	1,130	300	5¼
19	1.39	.97	.76	1.10	3.53	90.30	1.95	100	Middling, . . .	76,000	1,900	130	3¼
20	.85	1.07	1.60	–	4.70	85.85	5.93	100	Low middling, . .	2,497	250	23	2¼
Av.	.57	1.26	.80	.92	4.25	90.68	1.94				1,045		3¼

[Above test was made by running through two bales cotton in each case, except No. 6 and No. 15, where three and five bales, respectively, were used. Tare includes hoops and bagging. The amount of clean cotton averaged, from good middling stock 92.08 *per cent.*; from strict middling 91.37 *per cent.*; from middling 90.94 *per cent.*; from low middling 88.24 *per cent.*]

COST.

Mill.	Overseer.	Wages.	Opener Hands.	Wages.	Breaker Hands.	Wages.	Finisher Hands.	Wages.	Spare Hands.	Wages.	Total Cost per Day.	Cost per Pound.	Average Number Yarn Spun.	Openers per Man.	Breakers per Man.	Finishers per Man.
1	1	$3.00	5	$1.05	5	$1.05	5	$1.05	5	$1.22	$24.85	$ .087	14.00	2	2	4
2	-	-	2	1.04	1	.83	1	1.17	-	-	4.08	.064	37.75	2	4	4
3	-	-	1	1.00	1	1.00	1	1.10	-	-	3.10	.107	10.00	2	3	4
4	1	1.65	2	1.10	1	1.15	2	1.10	-	-	7.20	.064	32.00	2	4	3½
5	1	1.50	3	.83	3	.83	4	.92	-	-	10.16	.066	23.00	2	2	3
6	1	2.25	5	1.00	5	1.10	5	1.10	5	1.00	23.25	.071	12.00	2	2	4
7	1	2.08	4	1.25	4	1.25	5	1.25	3	1.25	22.08	.105	13.20	2	2	3
8	-	-	1	.75	-	-	1	1.00	-	-	1.75	.137	33.50	1	-	1
9	1	1.50	3	1.00	2	1.00	2	1.12	-	-	8.75	.072	20.61	1½	2½	3½
10	1	1.45	2	1.05	2	1.05	2	1.05	1	1.00	8.75	.058	28.34	3	3	4
11	1	3.60	6	1.00	6	1.05	6	1.05	5	1.18	28.10	.107	32.50	1	2	4
12	1	2.85	6	1.05	6	1.05	6	1.02	8	1.10	30.37	.100	23.00	2	2	4
13	1	2.00	4	1.00	3	.95	5	.97	7	.86	19.72	.096	20.96	2	3	4
14	1	1.50	3	1.00	3	1.00	2	1.08	1	1.00	10.66	.116	23.50	2	2	4
15	1	3.00	12	1.00	6	1.05	5	1.05	12	1.15	40.35	.115	15.60	1	2	5
16	1	1.48	5	.80	2	.93	3	.98	1	.80	11.08	.081	34.00	1	3	3
17	-	-	5	.85	2	.92	3	1.00	2	.87	10.83	.122	28.56	1	3	3
18	1	2.05	8	1.12	4	1.25	6	1.20	6	1.05	29.51	.117	17.00	1	2	3
19	1	1.35	5	.90	1	1.05	2	1.05	3	.90	11.70	.093	32.48	1	5	5
20	-	-	-	-	1	1.00	1	1.00	-	-	2.00	.096	31.50	-	2	2

NOTE. — Of the twenty mills, Nos. 1, 2, 3, 7, 12, 13 have the preparer attached directly to the breaker picker without trunk; Nos. 4, 6, 9, 10 have the preparer and one twenty-four inch rigid beater attached to the breaker picker by a cleaning trunk; Nos. 16, 17, 18 have the flexible whipper beater, attached to the breaker picker by a cleaning trunk; Nos. 14, 15 of the mills have both the preparer and one beater with a cleaning trunk, and also the whipper beater, with a cleaning trunk running side by side. Of the remaining five mills, No. 11 has the preparer and one beater attached directly to the breaker picker without trunk, forming the so-called duplex pattern, and in addition to this the stick-whipper used as an opener; No. 8 has a single beater, similar to the Lord opener, attached to the breaker picker by a cleaning trunk; No. 5 has a "scratcher" in place of the porcupine beater in the preparer attached directly to the breaker picker without trunk; No. 20 has the whipper beater attached directly to the breaker picker without trunk; and No. 19 has the whipper beater and one rigid beater attached to the breaker picker by a cleaning trunk; so that out of the twenty mills there are eight different arrangements for opening, not including the method of using three processes, a breaker, an intermediate, and a finisher.

Mr. H. C. Perham. I have listened to the reading of the "Investigation of Pickers" made by Mr. Reed, with a great deal of interest, and while it shows a vast amount of work, is very creditably written and treats the subject in nearly all its details, it fails to give us any information whatever in regard to the evenness of laps found in any one of the twenty mills enumerated. It also fails to show any comparison between mills using the Three-process System and Two-process System of picking, only one mill (No. 3) being cited as using intermediate machines. Now I think these two points play pretty important parts in the question of picking. Since the introduction, or, I might say, the more general adoption of the revolving flat card, greater attention has been paid to the evenness of picking by both the machine builder and manufacturer, and the result has been that a great many mills have adopted the Three-process System in order to get more doublings and an extra evener; that is, an evener on the intermediate machine.

As far as my experience goes, nearly all the mills at the present time adopting the English system of carding are using *fewer beaters* in their system of picking, and *more machines*, sometimes working as few as one beater in each of the breaker, intermediate and finisher machines, but more generally two in the breaker lapper and one, each, in the intermediate and finisher lappers; doubling three or four into one through eveners on the last two machines.

In other mills, where the opening and finishing are located on different floors, the same finishing process is retained, but an additional beater is often supplemented in an opener, which is connected by a cleaning trunk to the breaker lapper, making a system of five beaters.

Having had occasion lately to divide several two-beater finisher lappers into single-beater machines, I made a few weighings between the two systems, using the same breaker laps in both instances and the same evener throughout, thus forming a fair comparison. The machines were the Kitson-Lord pattern, with

the Kitson solid-roll eveners, and ten consecutive yards from the two-beater finisher weighed, respectively, 13½, 12⅞, 13½, 13, 13¾, 12⅞, 13¼, 13½, 14, 13⅝ oz., the extreme variation being 1⅛ oz.; and from the single-beater finisher, the breaker laps first passing through an intermediate machine, the weights obtained from ten consecutive yards were 12⅞, 13¼, 13½, 13½, 13⅜, 13¼, 13⅜, 13⅛, 13½, 13⅜ oz., the extreme variation being ⅝ of an oz.,—showing in favor of the Three-process System, with an evener, which we class to-day as next to a geared-up roll feed. I have made weighings in three other mills fitted up with Three-process picking, as follows: Kitson make, Walker & Hacking pattern, with Clarke & Perham sectional eveners, four beaters in the whole system; ten consecutive laps from the finisher lapper weighed, respectively, 14¼, 14½, 14½, 14½, 14½, 14¼, 14½, 14½, 14½, 14½ oz., extreme variation being ¼ of an ounce. In another mill, having Kitson-Lord pattern machines, with Clarke & Perham sectional eveners, three beaters and preparer making up the whole system, ten consecutive yards weighed, respectively, 10, 10¼, 10⅜, 10⅜, 10¼, 10¼, 10¼, 10⅛, 10⅛, 10⅛ oz., showing an extreme variation of ⅜ of an ounce; and in the third mill, which was fitted up with the Kitson New Model duplicate-part machines, with Clarke & Perham sectional eveners, five beaters and preparer making up the system, ten consecutive yards weighed, respectively, 14⅛, 14⅛, 14⅛, 14¼, 14⅜, 14¼, 14¼, 14⅛, 14⅛, 14¼ oz., extreme variation being ¼ of an ounce. The mill first reported is the only one that has come to my notice having both processes of picking on the same work, and if any gentleman present has any data on this subject I should be pleased to hear from him.

The President. I should like to call the attention of members to the table on page 19 on "Waste," which I think covers several quite important points. That table was prepared by Mr. Reed very carefully. It is a subject in which he took a great deal of interest, and he thought that table was, perhaps, the most valuable one there was in connection with his report. There is one matter, which will be found in a note

at the bottom of the page, which I think is of interest, showing the percentage of waste which comes from the different qualities of stock. You will see that there is quite a uniform variation in the quantity of clean cotton for working that comes from middling, low-middling and strict-middling. Then there is another matter in connection with the table that I noticed as I was looking it over, and that is, the relative amount of waste that is obtained from those mills with a trunk and those without a trunk. I have always supposed that the trunk took out more waste than was taken out without it; but in looking over this report I see that in all those mills where they have the trunk, while there is a certain amount of waste taken out by the trunk, there is always a certain amount of waste unaccounted for, and taking the two quantities together and adding them up we find that the total amount of waste included in the two columns, — that is, the column giving the per cent. of waste from the trunk and the per cent. unaccounted for in all the mills using trunks, — was 1.99 per cent., while in the mills that were not using any trunk, those columns contain 3.11, which would seem to show that there was really more taken out without the trunk than there was with it. I then took the mills using good middling cotton, of which there were two with the trunk and one without, and the result shows that with the trunk there was 1.48 per cent., and without the trunk there was 1.65 per cent. That same thing follows through all the other grades of cotton. It is rather a curious result to me. I do not know how it is with other people, but if anybody has anything to say on that point I should be glad to hear from him, because I think it is rather an important matter.

A Member. Do I understand the mill numbers represent the same mills all the way through?

The President. I understand that is the case; in fact, I know it is the case. It was thought desirable in making the investigation not to give the names of the mills, as some people objected to having the details put down if the name of the mill

was known, and the tables have been arranged so that all the details in regard to the different mills can be followed through by paying attention to the numbers.

Mr. ATHERTON. Mr. President, a number of years ago Mr. Sawyer, of the Appleton Company, wanted to find out whether there was any merit in the trunk; so he had two machines built, and he wanted us to open one of them — that is, separate it into two sections — and put in a trunk, and test it alongside of a machine which was just exactly as that machine was before it was changed. We did so, and put in about fifty feet of trunk. We ran those two machines together, and weighed the cotton before we put it in and weighed the waste, and there was no difference whatever in the result. In the case of the machine that had the trunk the waste went into the trunk; there was scarcely any under the machine. Where the trunk was not used there was quite a lot of dust under the machine, of just exactly the same kind as that which was found in the trunk of the machine that we put the trunk into; showing, in that case, that the dirt was simply transferred to the trunk which would have gone out into the dust room and down under the machine.

The PRESIDENT. These questions in regard to the use of a trunk are of some importance, because a trunk costs something, and if we are only going to get out the same amount of dust any way, we should not want to lay out money in putting in a trunk.

Mr. PERHAM. I presume Mr. Atherton's statement is all right, but I would like to ask the question why Mr. Sawyer adopted trunks in the Appleton Mill shortly after this experiment?

Mr. ATHERTON. I cannot say, unless the trunks he put in were better than the one we put in. They were made exactly the same; I do not know any difference. Mr. Sawyer may have changed his mind in regard to them; but, certainly, at that time, the result showed that there was no difference whatever. We changed the machine back again to what it was

before. He did not see any benefit to be derived from the trunk and we took it out at that time.

The PRESIDENT. If there is no further discussion desired on this subject we will proceed to the next paper, which is on the subject of "Leather Belting," to be read by Mr. SCOTT A. SMITH of Providence, R. I.

LEATHER BELTS.

HOW TO DETERMINE THE RELATIVE VALUE OF DIFFERENT MAKES.

By SCOTT A. SMITH, Providence, R. I.

At recurring intervals since 1863, when I first commenced to make use of belts, I have sought for information to exactly determine the comparative value of different makes.

It often happens that much is known round and about a subject but the exact reasons why are not understood. This statement is well illustrated by the fact that American tanners and curriers of calf-skins have never been able to solve the mystery connected with the great superiority of those tanned and curried by the French.

In July, 1887, I published, in "Power and Steam," the first printed statement of the exact action of oils and greases on belt leather in the currying processes, including the chemical changes which then take place. From that article I make some extracts which bear directly on this subject.

The fibres of skins interlace in all directions; each fibre consists of a number of filaments. Dry uncurried leather has little strength and may be torn as easily as paper, when the respective thickness of the two materials is considered. Dry uncurried leather has fibres which are easily disintegrated into separate filaments; each fibre is also loosely held to place in the tanned hide which has distended pores and spaces.

A tanned hide when received by the currier should be thoroughly washed, shaved and scoured by him to remove all uncombined matter, then it is allowed to dry to a suitable state

of moisture, after which, with proper manipulation, it is greased and hung up to dry. As the moisture goes out the grease enters into the leather by capillary attraction. The same advantageous resulting effect cannot be had except in the above way; to put grease upon dry uncurried leather does not answer, in any measure, the same purpose.

Tallow and cod oil are accepted as the greases best suited for currying tanned leather intended for belts. It is, almost wholly, the oleine, or oil of tallow, which enters the leather. Nearly all of the solid part, or stearine, remains on the surface and is scraped off. Some of it is carried into the leather, but afterwards works out, to appear on the surface as a white substance. The stearine has, however, served this very useful purpose, to hold the grease to place on the surface of the suspended hide, to cause an equal distribution of the oil.

The oleine of all oils will oxidize, or gum, and cod oil is well suited to work with the oleine of tallow to that end. An excess of the oils is carefully avoided. These oils oxidize very rapidly from being distributed over an almost limitless number of filaments of a moist hide.

The fibres are thus coated with an elastic gummy substance, which not only strengthens each filament and fibre, but binds them together by its adhesive quality. The fibres may not be easily broken by bending as the initial rupture is prevented by the elastic surface of the gummy oil.

Each fibre has an elastic toughened character, and under a delicate sense of touch, when drawn between the fingers, it gives a positive evidence of being coated with a varnish-like substance. A powerful microscope shows that the fibres of curried leather have a rounder, fuller form than those from uncurried leather.

An additional reason for the strength of curried belt leather is that the elastic quality imparted to the fibres by the oil allows a strain to be distributed through all the fibres.

By the consolidating forces applied in the currying and finishing processes the interlaced fibres are locked to place and held to those in contact with them by the elastic gummy oil.

It has seemed incumbent on me to add to the above by indicating in what manner the relative value of different makes of belts can be determined, aside from the well-known ways of judging by examining a roll of belt to see if the leather is of uniform thickness, if there is an absence of soft places, if it is supple in its character, if the joints are well made and the belt is reasonably straight.

For the making of the best belt leather the hides of the half-wild Texas steers are used, as possessing the best qualifications. From the moment of their being taken from the animals, and until they reach the tanners' hands, they receive a systematic and correct treatment to keep them in the most suitable condition.

It is a fact established, — established by long experience, — that oak-tanned leather is the best for belts; that is to say, it is superior to hemlock tannage, or any other method. The tannin principle in oak bark gives to leather the strongest and most enduring fibre.

As before stated, dry uncurried leather has little strength, hence the better the currying the greater the strength and enduring quality of the leather. For superior currying the best quality of white selected tallow with the best cod oil are necessary. It can be readily understood that both the oil and grease are thoroughly combined with the fibre and cannot be forced out of the belt by contact with a solid body, such as a pulley face, or be absorbed by dust, nor readily change by atmospheric influence; the oils have, as before explained by me, become a component part of the leather; thus it will be seen that a properly curried belt cannot have any free oil.

A custom has prevailed, to a limited extent, of running a finished belt through hot tallow to give it extra pliability and immediate tractive power on a pulley face. This process gives a very false value. In this hot application the stearine of the tallow is carried into the belt, where, as before stated, it has no legitimate place; it is an active acid quality in tallow. All such oils and greases put upon dry leather gradually undergo

a change from atmospheric influence, by which they develop a free acid injurious to the fibre.

The best belting has a fine finish, particularly on the grain side. There is real utility in the labor necessary to produce it. Much hand labor must be expended upon leather to consolidate all the fibres and the gummy oil into a homogeneous mass.

The best belting has an unmistakable light buff color, which indicates that it is not only all oak-tanned, but that the leather has been thoroughly washed by the currier to remove all matter except the fibre. The light buff color also indicates that only the best quality of greases have been used; if the latter are of inferior quality they darken and impair the leather.

The best belting has a firm, solid character, while at the same time it is pliable. As it is the nature of leather to possess a degree of elasticity, it is reasonable that a belt should stretch to some degree under strain, and while a well-made belt must be reasonably rigid against stretching in use, yet to take all the stretch out of a belt in its manufacture would imply to strain it beyond the just limit due to its nature.

Hemlock-tanned, also what is known as chemically-tanned, leather, are each treated with sumach or with oak-bark extract, to give the leather a surface color resembling oak-tanned leather. But once you become familiar with the true buff color of oak-tanned leather you need not be deceived.

The cracking of the grain side of belt leather, when bent at a sharp angle, is due to the fact that the grain is thicker on some leather than on other, — it grew that way on the animal; also the thicker the leather is the more liable it is to crack in the grain, but if the grain (hair) side of single belts is run to the pulley face then there is no cracking of the grain unless under undue strain.

The final tests for the best belting are as follows: Take a piece, say two inches wide by eight inches long, and cut it down four inches into two strips, each one inch wide, and submit the leather to a tearing strain. If of the best grade, with respect to quality of hide, quality of tanning and quality of

currying, then it will have great power of resistance; if torn then most of the fibres will not pull out but will break, because they are thoroughly united to each other by the gummy oil. If in the tearing strain the fibres pull out to a great extent, that is an indication of imperfect or incomplete currying, although the original quality of the tanned hide might have been good. A poor piece of leather tears easily, and a majority of the fibres break short off.

A final and conclusive evidence is to test the fibres themselves by seizing them with the fingers at the place of rupture, and subjecting them to a breaking strain. In a poor piece of leather the fibres have little strength, which is easily perceptible.

The difference between different methods of currying belt leather may be best appreciated when knowing that in some cases only about eight days are consumed in the processes, while in the hands of the best curriers about four weeks are needed.

In conclusion, it seems proper to state that the cost of hides of the best quality may be all of twenty-five per cent. more than those of the lower grades. Add to this the diminished cost of cheap tanning processes, cost of cheap greases, cheap and diminished labor in the currying, and you can easily see why one firm may undersell another and still make a large percentage of profit at the lower price.

The President. Gentlemen have heard the paper. Are there any remarks to be made upon it?

Mr. Hervey Kent. Mr. President and Gentlemen: You will notice that on the fifth page of the paper that has been read there is rather a bold statement, unless the gentleman has some facts by which he can substantiate it. At least, it is entirely opposed to any experience that I have had. You will notice that he says here: "It is a fact established, — established by long experience, — that oak-tanned leather is the best for belts; that is to say, it is superior to hemlock tannage, or any other method. The tannin principle in oak bark gives

to leather the strongest and most enduring fibre." It may be that I have never had any pure oak-tanned leather belting; but what little experience I have had has been entirely opposite to that statement; that what passes for oak-tanned leather has not the capacity to stand the lacing nearly as well as hemlock-tanned. I have no doubt that you might find an oak-tanned belt that would be a great deal better than some hemlock-tanned belting, but all the experience that I have had goes to show that hemlock-tanned leather is the toughest and will not tear out where it is laced as soon as oak-tanned; I have some belts that have been running fourteen years, driving warp spinning, made out of hemlock-tanned leather. Some of them have been taken up but twice. None of them have torn out where they were laced, and they give us no trouble. A mere statement, of course, amounts to nothing, but if any gentleman who has a hard place for a belt will take what is commonly known as oak-tanned leather for one-half of his belt, and take for the other half hemlock-tanned leather, and put it on and run it, I think he will be satisfied that the hemlock-tanned is the toughest. I have known it to be tried on lug-straps for a loom. Oak-tanned leather looks very nice. I know one man who put oak-tanned leather on one side of his looms, near the spare floor, because it looked so well, and hemlock-tanned on the other side; but the oak-tanned very soon gave out; it seemed to crack and break. By the way, I have no interest in hemlock-tanned belting, as far as that is concerned. There is a party in Boston who has six ten-inch belts running. He went to one belt maker and ordered three ten-inch belts of hemlock-tanned leather, saying nothing to him about wanting any more. Then he went to another man and told him he wanted three ten-inch oak-tanned belts, and told him that he had ordered three of the other man, so that he gave him a little advantage. Those six belts were put on the machines, and within six months the lacing gave out in the oak-tanned, and the other ran years without tearing out.

I had a little curiosity in this matter, and went into a belt shop this morning and saw some tests, while there, with two

pieces of leather, one oak-tanned and the other hemlock-tanned. They were put together, laced, put into a stretching machine, and in every instance the oak-tanned gave out. Now I do not know but the gentleman has some facts to sustain his statement. If he has, I would like to hear them.

The PRESIDENT. We would be glad to hear from Mr. Smith or any other gentleman who has anything to say on either side of this question.

Mr. KENT. What we want is the facts.

The PRESIDENT. I do not know why this question of oak-tanned and hemlock-tanned leather should be left undecided. There are a good many gentlemen here who are using belts who must have some views which they can express. I do not know why the question may not be as well decided now as at any time, if anybody can give us the necessary points.

Mr. KENT. There is other testimony bearing upon this subject, that I omitted to refer to. I asked a tanner of large experience to explain what he thought the practical difference would be if he should divide a skin in the middle, tan one half with oak bark, the other with hemlock. He said the oak would come out the thickest, while the hemlock would weigh the most per square foot. The oak seemed to puff up the grain, while the hemlock seemed to contract it. The tendency of the former was to make the fibre brittle, while the hemlock made it tougher; which explains why, when the two kinds are laced together and the tests made, the oak gives out. He said if he was belting a mill for himself, he would give 50 per cent. more for the hemlock-tanned leather. He had formerly supposed that he must have oak-tanned belting, as that was the best. He tried it for twenty-five years, and for the last few years he had discarded it entirely and adopted hemlock-tanned belting.

A MEMBER. I would like to inquire of the gentleman if he would use any wider hemlock-tanned belting than if he was using oak-tanned belting.

Mr. KENT. No, sir; by no manner of means. I would like the testimony of this Association on this matter. What a man

says amounts to nothing unless he has something to back it up.

Mr. SCOTT A. SMITH. My attention was turned to this matter many years ago, by a relative who was a tanner and whose special business it was to make leather for belts. He told me that after it became difficult to get oak bark as readily as hemlock bark, that he then commenced to use oak and hemlock, called union tanning. He added that he was sure it was as good or even better than pure oak-tanned leather. When I went into business in Philadelphia in 1863, I sent to Providence for belts made in that way, and continued to do so for several years; but I could not get the endurance out of them, under severe labor, that I could out of all oak-tanned belts. With reference to all hemlock-tanned leather being laced to oak-tanned leather, and the oak-tanned tearing out first, that would not be a conclusive proof to my mind. I have seen leather which would stand a very great tensile strain, much greater than another leather; but when put to work, that which would stand the greatest tensile strain would not last nearly as long as the other.*

The PRESIDENT. If there is no further discussion we will proceed to the next paper, which will be read by Mr. GEORGE H. BARRUS of Boston, on "Steam Boiler Tests."

* Oil added to belt leather, after the regular and proper currying process, will give "for the moment," increased tensile strength; also a half-curried belt, having a certain amount of free oil, might show great strength against tearing out in the lace holes under *excessive* strain; but neither of these cases prove that such a result so obtained is the thing to be desired. S.

A PAPER ON BOILER TESTS,

ILLUSTRATED BY THE RESULTS OF 140 EVAPORATIVE TESTS CONDUCTED BY THE AUTHOR.

By GEO. H. BARRUS, S. B., Boston, Mass.

In the pursuit of his business as a steam engineer, the writer has had frequent occasion during the past ten years to make evaporative tests of steam boilers. The interests which have led to the work are of a varied character. Inventors or builders of new types of boilers have been desirous of learning what economical features their improvements possess, and they have called for the results of an evaporative test as a means of comparison with the performance of existing boilers; or, knowing themselves the economy of the improved generator, they wished, for purposes of trade, to corroborate their own testimony of its superiority, by the certificate of a disinterested engineer. Managers of factories have sought advice upon the cause of excessive consumption of coal in their steam plants. To solve this problem it is necessary to ascertain the evaporative efficiency of the boilers, so as to separate the process of generating the steam from that of its use after generation. They have also desired information upon the general economy of their boilers, and upon the kind of fuel which it would be most advantageous to burn, when all the questions of current price, evaporative efficiency and incidental advantages and objections are taken into account — questions which can be determined satisfactorily only by means of an evaporative test. They have had occasion, too, before completing a settlement with the contractor for a new plant of boilers, to call for a test, to ascertain whether in capacity or economy, or both, the boilers do their work in the manner stipulated in the contract. They have also sought information, which only an evaporative test affords, to guide

them in the selection or arrangement of a contemplated new boiler plant, or in the renewal of an old plant. Capitalists have called for evaporative tests upon improved forms of boilers, in which they have in view the investment of money, that they may learn from outside investigation whether the inventor's claims are well founded, or whether the improvement is of sufficient merit to warrant the investment. Finally, a large class of persons, bent on seeking information, have had boilers tested, so as to find out whether, in one way or another, the evaporative efficiency could be improved.

In every case, whether the test has been made at the solicitation of the inventor, the mill manager, the capitalist or the investigator, there has always been one controlling object in view on the part of the writer, and that is, the determination of the true performance of the boiler; and the work has been undertaken in almost every instance with the unbiased feeling of a student, interested only in getting at the facts.

In this work the number of individual tests which have been made has reached a sum between three hundred and fifty and four hundred. Many of them have been made in the New England States. The boilers have been situated in cotton mills, woollen mills and other textile factories, paper mills, machine shops, lumber mills, rubber works and public buildings. They have embraced plain cylinder boilers, horizontal return tubular boilers, locomotive boilers, vertical tubular boilers, water-tube boilers, sectional boilers and patented boilers of various kinds. They have been set in brick-work, set without brick-work, set according to patented methods and set in the ordinary way. They have been fired with anthracite coal of various kinds and sizes, bituminous coal of various kinds, anthracite screenings, mixtures of anthracite screenings and bituminous coal, petroleum oil and coke.

The paper is devoted to an analysis of many of these tests. Of the number referred to, those which are omitted are either of a private nature or are devoid of general interest. They were all conducted personally by the writer, with the exception of one set of tests, which was made by an assistant who worked under the writer's direction.

The tests are so varied in object, in conditions, and in type of boiler, that it has proved advisable to take up each boiler and the tests made upon it, separately, and give, as briefly as a clear presentation of the subject warrants, the general features and dimensions of the boiler, the data and results of the tests, and memoranda of the main points of information which the tests reveal. Much of the material in the accompanying pages consists, therefore, of tables of boiler dimensions and boiler tests. Given in this form, the reader will find means for studying the subject, if desired, from his own standpoint. The special object of the paper is an examination of the tests as a whole, and a classification of the data and results, so as to put in connected shape the information which they give as to the conditions which govern the economical generation of steam and the best practice in boiler engineering.

Before entering upon the proposed examination, the general subject of boiler tests and the methods which were employed in conducting the tests under consideration demand attention.

The object of all boiler tests, first sought, is the determination of the weight of water evaporated by a pound of coal. The object ultimately sought varies in different cases. Some tests have in view the determination of the efficiency of the boiler as a generator of steam, when operated under such conditions of quality of fuel, kind of firing, capacity and general management as will give the best result. These determine the true efficiency of the generator. Others have in view the general result produced by the boiler, however much it is affected by disturbing causes, and they determine the economy with which the fuel is burned, whether the type of boiler, kind of fuel, capacity, mode of firing and management are favorable or unfavorable.

Owing to the two general objects named, boiler tests might be divided to advantage into two classes. The first might be termed the *engineering test*, being of greatest interest to the engineer, who must know the true efficiency of the boiler to intelligently lay out his plans. The second might be termed the *commercial test*, being of most interest to the manufacturer

or steam user, who must know how the coal is used which he has to purchase.

In conducting the engineering test, the boiler should be worked with a standard quality of fuel. It should be clean on both the interior and the exterior surfaces. It should be fired by a skillful fireman, who should use every exertion to obtain the highest efficiency from the fuel. It should be worked at such a capacity as will secure the most favorable result. The boiler should be worked long enough in preparation for the engineering test to heat itself and the material in which it is encased to its normal working degree. The fire should then be burned down to a low point and thoroughly cleaned, a thickness of 2 or 3 inches of clean burning fuel being retained for a foundation upon which the fire of the test is to be started. With this thin fire, the thickness of which is estimated as a basis for commencement, the test is begun. The boiler is then operated in the manner determined upon, for at least 24 hours, and the quantity of coal burned and water evaporated is measured. At the close of the test the fire is again burned down and cleaned, and this is done in such a manner that the condition and thickness of the bed of coal on the grate, as nearly as can be estimated, is the same as it was at the commencement of the test.

For the commercial test the boiler should be operated in the manner customarily followed, and the measurement of coal and water taken a sufficient number of days to give an average indication of the performance. In factory work a test of one week's duration is of suitable length. No change should be made in the daily hours of running, the mode of firing, the manner of treating the fires at night, nor in the general operation of the plant, the object being to include all these questions in the determination of the main point at issue.

If all tests could be made in accordance with these plans, nothing would be left to be desired. The relative efficiency of different generators would be known at once. The manufacturer would have no complaint to make because the results of the test do not correspond to those obtained under working

conditions. Unfortunately, no such uniformity of method can be established, on account of the practicable objections and expense involved in carrying on tests of this kind. The 24-hour continuous engineering test is usually out of the question in a mill which uses steam only 10 or 12 hours a day. The six days' commercial test is not to be thought of by the manager of a mill, who counts the expense for expert's services.

The ordinary calls for evaporative tests are for those which can be made in one or two working days, under conditions as near as possible to the existing ones in the locality where the boiler is placed. These must answer, in ordinary practice, for the purposes of both the engineering and the commercial tests in the scheme outlined above.

Nearly all of the tests referred to in this paper are of the last-named class. They were made, as a rule, in factories working 10 or 12 hours per day, where the fires are banked at night, and where an interval of about an hour occurs at noon time, when the production of steam nearly ceases. The boilers were generally cleaned, as far as the outside fire surfaces were concerned, by the use of the tube scraper or steam jet cleaner, preparatory to each test. The inside surfaces were not cleaned and generally were not examined. The mode of firing was not always the best, but it was always good; that is to say, the fires were, as a rule, free from "holes" or spots where the live coal had died out, with the exception of cases where fine grades of anthracite coal, such as chestnut No. 2 and pea, were used, in which there is frequently a tendency to this state of things, and the fires were kept at a thickness of not less than five or six inches. When bituminous coal was burned, it was usually fired on the "spreading" system, and the bed of coal was broken up and kept level when required, by the use of the slicing and stoking bar.

The method of conducting most of the tests given in the paper is as follows: Preparatory to the beginning of the test, on the night before its commencement, the fires are burned out at the close of the day's work. The furnace and ash-pit doors and the dampers are closed during the night, and, in case only

one or two boilers of a plant are tested, the stop valves are also closed, shutting the steam into the boiler. At some convenient time during the night the furnace and ash-pits are cleaned. At five o'clock in the morning, or at a sufficiently early hour to get up steam for the day's work, the new fire of the test is started with enough pine wood to cover the grates, and coal is fired at once, and the boiler brought to normal action. Oftentimes the fire is in working condition before the steam can be disposed of, and a pause ensues until the usual work of the mill begins, during which time the fire is covered with new coal, and the draught choked by shutting the damper and opening the fire doors. During the noon hour, when the works are stopped, the fire is cleaned (if needed) and covered with new coal, and the draught checked in like manner. As the hour for stopping draws near, the fires are carefully burned down, so that at the close of the day's work they are nearly out. As soon as they are finally extinguished, the contents of furnaces and ash-pits are removed and the doors and dampers closed for the night, and in the cases noted the stop valves are shut. When the coal is moist, a sample is selected and dried for 24 hours, and the quantity of moisture is determined by a comparison of the wet and dry weights. A sample is taken of the ashes and unburned fuel removed from the furnaces and ash-pits at the close of the test, and sifted through a screen having $\frac{3}{8}$-inch meshes. The proportion of unconsumed coal which fails to pass through the screen is determined and applied to the total quantity, and the whole weight of unconsumed coal thus found is deducted from the weight of coal fired, to determine the net quantity consumed. The value of the wood used for starting the fires is taken to be equivalent in coal to $\frac{4}{10}$ of its weight.

At the time of starting the new wood fire of the test, the position of the water line as shown in the gauge glass of the boiler is carefully noted, and the pressure indicated by the steam gauge as well. At the close of the test, it is intended that a sufficient amount of water shall be supplied, so that when the time arrives on the next morning, corresponding to the time

when the test was started, the position of the water line and the indication of the steam gauge shall be the same as at the beginning. The last observation of the test is thus made 24 hours after the time of the first observation, when the condition of the boiler is presumably the same. If the water line occupies a different position, a suitable correction is applied to the weight of water measured, which is determined by computing the quantity from the volume which it occupies, calculated from the known dimensions of the boiler. If there is a difference of pressure, no account is taken of it, unless the difference is large; in which case, the quantity of evaporation is computed which would take place if the stop valve were opened and a sufficient amount of steam let off to reduce the pressure from the higher to the lower point. In conducting a test according to this method, the small quantity of evaporation which takes place during the night, produced by heat stored in the boiler at the end of the day's run, is included in the total evaporation of the test.

During the progress of the test the feed-water is weighed previous to its supply either to the pump or injector which feeds it. The weighing apparatus consists of two tanks, one of which rests on a platform scale, which is supported by staging raised above the level of the other. The water is first drawn into the upper tank. Here it is weighed and then emptied into the lower tank. Thence it passes into the suction pipe of the pump or injector, which is temporarily changed from its usual connection for the purpose.

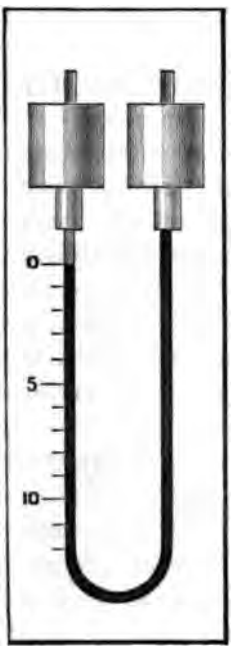
All pipes connected with the feeding apparatus, except those concerned in the work of the test, are disconnected; and if this cannot be done, the tightness of valves which must be depended upon is first assured. If the blow-off valve leaks it is plugged.

In cases where an injector is used, and where there is no heater connected with the boiler, the temperature of the water is taken at its entrance to the lower tank. If a heater is used, the temperature is taken at its entrance to the boiler, a thermometer being set in the feed pipe for this purpose. If both injector and heater are used, the temperature is taken at the tank

and at the entrance to the heater, in addition to that of the water entering the boiler. To avoid breakage, the thermometer is placed in a cup filled with oil, which is set in the pipe.

The temperature of the escaping gases is determined in a few cases by means of a pyrometer, the stem of which is wholly exposed to the gases in the centre of the flue. In general, the temperature is obtained by means of a high grade thermometer set in an oil pot filled with cylinder oil, which is lowered into the centre of the flue. The pot is withdrawn when the thermometer is read. When a pyrometer is used, it is verified by comparisons with a thermometer.

The draught suction is determined by means of a U-tube gauge, connected to the flue between the damper and the boiler [see cut]. This tube, which is made of glass, is provided with enlarged chambers at the top, arranged so as to give a magnified indication of the vacuum produced by the draught. The instrument is filled with two liquids of different color, one liquid occupying the whole of one side of the instrument, and that part of the other side to near the top of the U-tube; and the other liquid occupying the remaining space in the U-tube and the opposite chamber. When connection is made to the flue (the proper side being connected), the line of division between the two liquids, which, owing to the differences of color and character, is clearly defined, moves downward in the tube and shows by the distance traversed the magnified amount of vacuum which is acting. The amount by which the true indication is multiplied depends upon the relation which exists between the diameter of the two chambers and that of the two legs of the tube. An instrument which multiplies eight times, which is a sufficient increase, gives a movement of 4 inches for an actual



draught of half an inch; that is, for a draught corresponding to the pressure of a column of water half an inch high.

The quality of the steam, in the case of boilers giving superheated steam, is determined by taking its temperature. A thermometer is inserted for this purpose in an oil cup, which is screwed into the main discharge pipe. The quantity of superheat is the number of degrees which the indicated temperature is in excess of the normal temperature. The normal temperature is that indicated by the thermometer when the boiler is under steam of the average pressure, at a time when the production has ceased, that is, when the steam is in a saturated condition.

In the case of boilers which do not superheat the steam, the quality is determined by the use of a calorimeter. The form of calorimeter employed is sometimes the barrel calorimeter, but preferably the continuous superheating calorimeter, devised by the writer some two years ago. The barrel calorimeter consists of a common oil barrel, fitted with an outlet valve, together with delicate scales and a finely graduated thermometer. A series of tests is made, one following after the other as rapidly as possible. The barrel is first filled with water to the desired point and the water heated in preparation for the tests. This water is let out and thrown away. The barrel is then filled again and the average temperature of the incoming water is taken, read to tenths of a degree, and the weight of water drawn in is carefully determined. After blowing out the condensed water from the pipe which is provided for supplying the calorimeter, the movable piece of pipe which conducts the steam into the water is attached, and the valve is opened for the formal conduct of the test. The water is heated to about 110 degrees. Then the valve is shut, the movable pipe unscrewed, the water stirred and the temperature carefully observed. The weight is taken, and the quantity of steam condensed is found by subtracting the previous weight. Each test of the series is conducted in the same manner, except that the preliminary heating is required for none but the first test, and the results are averaged. To compute the percentage of

moisture, the weight of cold water drawn in is multiplied by the number of degrees difference between the two temperatures observed, and the product is divided by the weight of con-

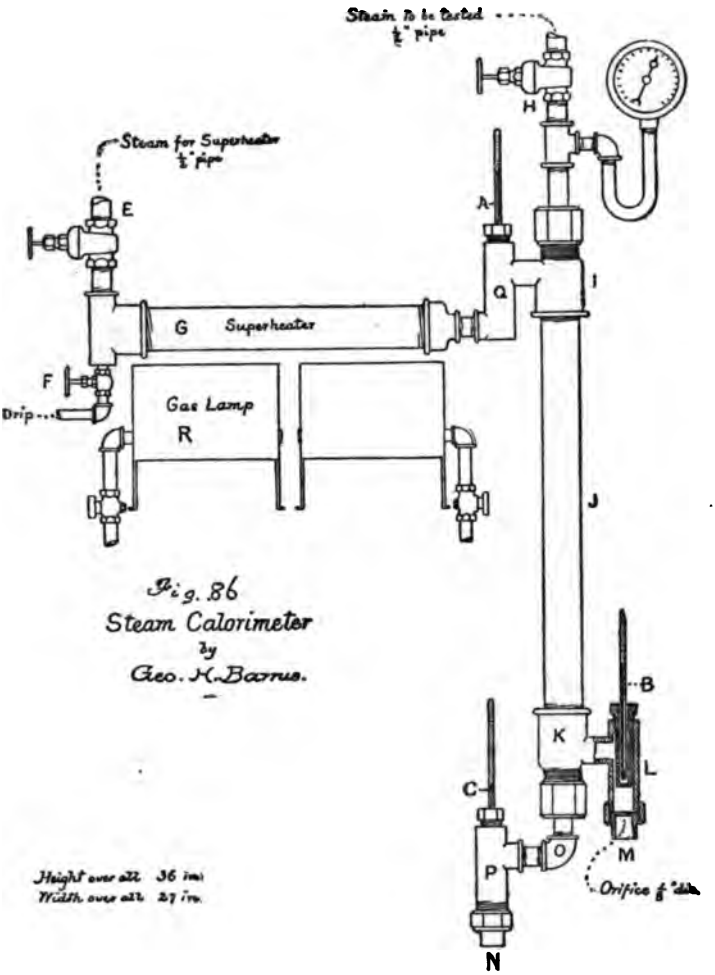


Fig. 86
Steam Calorimeter
by
Geo. H. Barrus.

densed steam. To the quotient is added the temperature of the heated water, and the sum thus found is subtracted from the total heat of saturated steam of the observed pressure (reckoned from zero). The remainder, divided by the latent heat of the same steam, gives the proportion of moisture.

The superheating calorimeter [see cut, p. 43] works on a different principle, requiring no water and no weighing. It consists of a heater, through which the steam to be tested is passed, and in which the moisture contained is evaporated. This apparatus determines the quantity of moisture, by first measuring the quantity of heat expended in evaporating it, and this is readily done by supplying the heater with steam previously superheated and observing the fall of temperature which the steam suffers in passing through the heater. The principal data required are the temperatures given by three thermometers, which do not need to be of delicate construction, nor to be read with extreme care. The quantity of moisture is readily determined to a small fraction of one per cent., since a fall of some 18 degrees in the temperature of the supply of steam to the heater is required for one per cent. of moisture.

The steam which is supplied to the calorimeter, whichever form is employed, is taken from the main discharge pipe of the boiler by means of a well-covered half-inch pipe. A long thread is cut upon the pipe, and it is screwed into the main so as to extend across the whole diameter of the pipe, and the enclosed portion is perforated. In this manner the points of supply are distributed and a sample of the steam is obtained.

Referring to the various tables of results given in the paper, some explanation is needed as to the meaning of the lines and the method of computation employed.

When the "manner of start and stop and kind of run" is stated to be *ordinary*, reference is made to the method just described, the tests beginning early in the morning, after the boiler had stood with no fire and with closed dampers during the preceding night, and with no preliminary heating; there being an interval at noon-time when the production of steam nearly ceased, and the night evaporation being included in the total. When "manner of start and stop and kind of run" is *ordinary with preliminary heating*, the method is the same, with the exception that the night evaporation is not included in the total, and the boiler is heated for a time preparatory to the beginning of the test. This is true also when the start and

stop is made with a thin fire. When the "kind of run" is stated to be *continuous*, there is no interval in the production of steam at noon-time; and when it is spoken of as a *factory* run, reference is made to the case where the usual noon-day pause occurs.

The "duration" of the test is the time required to evaporate the total quantity of water, assuming the rate of evaporation which occurs when the boiler is doing its normal work. It is the quotient obtained by dividing the total evaporation by the weight of water evaporated per hour.

The quantity of "ash" is the refuse of the furnace and ash-pits left after deducting the unconsumed coal which fails to pass through a $\frac{3}{8}$-inch screen, and the percentage is found by dividing this by the weight of dry coal consumed, and multiplying the decimal fraction thus found by 100.

The quantity of "coal consumed per hour" is found by dividing the total quantity by the number of hours determined upon for the duration of the test.

The quantity of "water evaporated per hour" is found by taking the weight evaporated during those portions of the test when the boiler is doing its normal work, say, in the case of a factory working 10 hours per day, from 7.15 to 11.45 A. M., and from 1.15 to 5.45 P. M., and dividing this quantity by the number of hours covered by those periods.

The "horse-power" is determined by first computing the equivalent evaporation per hour, supposing the feed-water supplied at 100 degrees and evaporated at 70 pounds pressure, and then dividing this quantity by 30. This is the horse-power basis of rating established by the Committee on Boiler Trials, appointed by the American Society of Mechanical Engineers. The equivalent evaporation is found by multiplying the actual hourly rate by the total heat of the steam, reckoned from the temperature of the feed-water, and dividing the product by 1,110, which is the total heat of steam of 70 pounds pressure, reckoned from 100 degrees.

The observations of boiler pressure, the various temperatures, and the draught suction are made every half hour

while the boiler is doing normal work, and the results are averaged.

The water evaporated "per pound of coal from and at 212 degrees" is computed by multiplying the quantity evaporated per pound of coal by the total heat of the steam, reckoned from the temperature of the feed-water, and dividing the product by 966.

The water evaporated "per pound of combustible from and at 212 degrees" is computed by dividing the "water per pound of coal from and at 212 degrees" by the percentage of combustible in the coal; that is, by 100, less the percentage of ash, and multiplying the result by 100.

In the tables of dimensions, the area of heating surface given is that exposed to the fire and products of combustion, and not that exposed to the water or steam.

No attempt has been made in these tests to determine, by chemical analysis, the constituent elements in the composition of either the coal or the escaping gases.

The evaporative results expressed in pounds of water evaporated per pound of coal, include no allowance for superheating, in cases where superheating exists, and are not corrected for moisture when the steam is found to be wet. The quantities given as "water evaporated" are feed-water supplied, and, presumably, evaporated.

Having now considered in a brief manner the general subject of boiler tests, and pointed out the method of conducting the particular tests under notice, we may pass to the chief object of the paper; viz., a review of the various results, and a consideration of the general subject of economy in the generation of steam, as revealed by the tests.

1. Comparison of Boilers which produce Saturated Steam with those producing Superheated Steam.

The boilers may be divided into two general classes, according as they furnish saturated steam or superheated steam. The first class are, as a rule, of the horizontal tubular type, and the second class of the vertical type. In most of the

boilers which superheat, that is, vertical boilers, the superheat is obtained by sacrificing the water-heating surface, and providing a large area of steam-heating surface. In the horizontal tubular boiler, the proportion of heating surface to grate surface is generally 33 or more to 1, and this is almost wholly water surface. In most of the vertical boilers, the proportion of water surface to grate is only 20 to 1, that of steam surface to grate about 10 to 1, making a total of 30 to 1, and this total surface is less than the ratio given for the horizontal boiler. Considering that the economic performance of the boiler bears some relation to the proportion which exists between the heating surface and grate surface, as is shown in a later part of the paper, the vertical boiler is handicapped at the outset by a deficiency of surface, even though the steam-heating surface is considered equally as effective as the water-heating surface. Let us make a comparison between the two types of boilers, however, taking the proportions which exist. Although the evaporation per pound of coal is less in the superheating boiler than in the boiler which does not superheat, it does not follow that the actual efficiency of one is different from that of the other. Superheated steam is of greater value than saturated steam, according as it is more or less superheated. The reason for this is, first, that superheated steam contains the greater amount of heat; and, second, that heat expended in superheating steam secures a greater return, in cases at least where it is used for power, than the original heat expended in evaporating the water. If, for example, steam is superheated 100 degrees, the added heat which it contains is 47.5 thermal units per pound, or 4.75 per cent. of the heat required to evaporate a pound of water, supplied at 212 degrees and evaporated into steam of 80 pounds pressure. In other words, if the boiler evaporates 10 pounds of water supplied at 212 degrees into steam of 80 pounds pressure, and superheats that steam 100 degrees, the excess of heat due to its superheat corresponds to an additional evaporation of 0.47 pounds of water. When superheated steam is used for motive power, the equivalent value of the added heat is more than the quantity named. Many engine

[illegible] degrees. A[illegible] per cent. moisture, the [illegible] efficiency of [illegible] per cent., and [illegible] horizontal boilers 3.8 per cent.

TABLE No. 1. — *Horizontal Tubular Boilers.*

Number of Boiler	Ratio of Heating Surface to Grate Surface.	Kind of Coal.	Percentage of Ash.	Coal per hour per square foot of Grate.	Temperature of Escaping Gases.	Water per lb. of combustible from and at 212 degrees.
				Lbs.	Degrees.	Lbs.
5, ...	33.8 to 1	Lackawanna, ...	16.7	11.1	482	10.73
6, ...	65.0 to 1	"	12.3	14.2	392	11.11
8, ...	67.6 to 1	"	15.5	9.4	335	10.39
9, ...	32.2 to 1	"	14.2	10.1	443	10.76
16, ...	60.9 to 1	"	8.1	14.5	373	11.00
18, ...	34.6 to 1	Lehigh, ...	9.4	14.0	349	11.24
19 av., ...	33.5 to 1	"	13.6	4.7	298	11.21
20, ...	35.5 to 1	– –	15.0	5.7	–	10.48
21 av., ...	37.6 to 1	Lehigh, ...	13.2	8.6	344	11.53
23, ...	42.0 to 1	"	10.1	12.2	346	11.20
26 av., ...	37.0 to 1	"	10.2	12.7	380	10.70
28, ...	26.5 to 1	White Ash, ...	10.1	12.9	455	9.75
42, ...	68.0 to 1	Lehigh, ...	12.9	11.5	350	11.03
44, ...	26.6 to 1	– –	12.0	7.9	474	9.87
46, ...	44.2 to 1	White Ash, ...	15.7	9.4	369	10.61
62, ...	47.4 to 1	Philadelphia and Reading, .	10.7	11.9	428	10.60
63, ...	57.9 to 1	" "	10.3	11.9	321	11.33
Average, . .	44.1 to 1		12.4	10.7	383.7	10.80

TABLE NO. 2. — *Vertical Tubular Boilers.*

NUMBER OF BOILER.	Ratio of Water-heating Surface to Grate Surface.	Ratio of Steam-heating Surface to Grate Surface.	Kind of Coal.	Percentage of Ash.	Coal per hour per square foot of Grate.	Number of Degrees superheating.	Temperature of Escaping Gases.	Water per lb. of combustible from and at 212 degrees.
					Lbs.		Degrees.	Lbs.
12, ...	20.6 to 1	9.3 to 1	Lackawanna, ...	8.6	11.1	90	480	9.56
13, ...	25.4 to 1	4.6 to 1	"	8.4	11.0	14	434	10.07
22, ...	32.3 to 1	15.6 to 1	Schuylkill, ...	11.6	15.4	42	478	10.13
30, ...	20.6 to 1	11.2 to 1	Lehigh, ...	15.1	9.8	89	449	10.54
31 av., ...	20.9 to 1	9.2 to 1	"	12.2	12.1	75	490	8.34
45, ...	19.9 to 1	11.3 to 1	Lackawanna, ...	17.0	12.0	65	520	9.17
Average, .	23.3 to 1	10.2 to 1		12.2	11.9	62.5	475	9.64

A more satisfactory comparison may be made if those of the horizontal tubular boilers, which have been called "double deck," are discarded, as also those in which the heating surface is deficient. Throwing out for this reason Nos. 6, 8, 16, 28, 42 and 44, the average quantities for the remaining eleven examples are as follows: ratio, 39.6; ash, 12.6 per cent.; rate of combustion, 10.2 pounds; temperature of escaping gases, 376 degrees; water per pound of combustible from and at 212 degrees, 10.94 pounds. Comparing the vertical boilers now with this new average, we have a difference of 99 degrees in the temperature of the gases, and 13.5 per cent. in the evaporation per pound of combustible. This makes the net superiority of the horizontal boilers 5.3 per cent.

The superior economy thus shown is evidently due in the main to the saving produced by the low temperature of the escaping gases. A difference of 99 degrees is amply sufficient to account for the difference in the results. For example, refer to the tests on boiler No. 59, which give the effect produced by utilizing the heat of the gases in warming the feed-water. Here a reduction of 107 degrees in the temperature of the gases secured an increase in the evaporation per pound of coal amounting to 7 per cent. Other cases are given where a greater reduction secured a larger saving.

It is clear that according to these tests, which are selected more or less at random, the vertical tubular boiler in practical use, having the proportions given, is less economical than the ordinary type of horizontal return tubular boiler; and this is true notwithstanding the superior value of the superheated steam which they give, for which the most favorable allowance has been made.

The comparison of average results which is given, attributes most of the loss to the waste heat of the gases, as indicated by their temperature; but the indication of temperature, according to the best view of the subject, is not a measure of the full extent of the loss. Owing to the brick setting with which the boilers are provided, and the tendency which hot brick-work has to become unsound by age, it is probable that, in practical

use, a large quantity of unneeded air is admitted through the brick-work, not only into the furnace, but into the flue space as well, which on one hand reduces the furnace temperature, and on the other hand lowers the temperature of the escaping gases. In this way a direct loss is produced by cooling the furnace; and further, the loss at the chimney, measured by the temperature, appears to be less than it really is.

There are two cases of vertical boilers in the paper, where the proportion of water-heating surface to grate surface is fully as large as in the best form of horizontal boiler, and the unfavorable influence of air leakage is prevented by the use of a fire-box. The boilers referred to are those numbered 47 and 73. The proportions of water-heating surface to grate surface are respectively 35.1 and 44.5 to 1. The temperatures of the escaping gases are respectively 423 and 427 degrees. The evaporations per pound of combustible from and at 212 degrees are both 12.29 pounds. Although these tests were made using high grades of bituminous coal, and for this reason cannot be fairly compared with those under consideration, the high character of the two results, contrasted with those referred to, brings out very clearly the fact of the inferiority of that type of vertical boiler which is deficient in heating surface and provided with a brick setting.

It would not be fair to conclude, that because the superheating boilers referred to are at a disadvantage when compared with those which do not superheat, this result must always follow. Were the loss from air leakage remedied by the use of a fire-box, there is good reason to expect that the vertical boiler furnishing superheated steam would be as economical as the horizontal boiler furnishing saturated steam, and it is not improbable that with suitable arrangement of surface, it would in the long run take the first place.

No data are given on either type of vertical boiler to show whether a considerable degree of superheating can be obtained, and at the same time a high evaporative efficiency. It is probable that the practical restrictions which the construction of the boiler imposes will prevent both of these objects from being realized at the same time.

It may be of interest, in passing, to note the effect produced by superheating the steam in an independent superheater. Under the head of boiler No. 2, reference is made to a test on a boiler fitted with an apparatus for this purpose. By increasing the quantity of coal burned 17.8 per cent., this being the coal used in the superheater, a superheating of 228 degrees was obtained. On the basis which has been taken for computing the value of the superheat, that is, a gain of one per cent. for every ten degrees of superheating, this steam has a value of 24.8 per cent. over that of ordinary steam. Here is a net gain of 7 per cent. in favor of the superheated steam.

2. General Conditions which secure Economy.

Glancing over Table No. 1, it appears that, in general, the highest results are produced where the temperature of the escaping gases is the least. A good examination of this question may be made by selecting those tests in which the temperature exceeds the average, that is, 375 degrees, and comparing with those in which the temperature is less than 375 degrees, taking first those boilers in the table which are of the common horizontal tubular type. It will be remembered that all of these boilers use anthracite coal of either egg or broken size. The tests with high temperature are given in Table No. 3, and those with low temperature in Table No. 4.

The average flue temperatures in the two series are 444 degrees and 343 degrees, respectively, and the difference is 101 degrees. The average evaporations are 10.40 pounds and 11.10 pounds, respectively, and the lowest result corresponds to the case of the highest flue temperature. In these tests it appears, therefore, that a reduction of 101 degrees in the temperature of the waste gases secured an increase in the evaporation of 6.7 per cent. This result corresponds quite closely to the effect of lowering the temperature of the gases by means of a flue heater in the case already noted, where a reduction of 107 degrees was attended by an increase of 7 per cent. in the evaporation per pound of coal.

TABLE No. 3. — *Common Horizontal Tubular Boilers, Anthracite Coal, High Flue Temperature.*

Number of Boiler.	Ratio of Heating Surface to Grate.	Kind of Coal.	Percentage of Ash.	Coal per hour per square foot of Grate.	Temperature of Escaping Gases.	Water per lb. of combustible from and at 212 degrees.
				Lbs.	Degrees.	Lbs.
5,	33.8 to 1	Lackawanna,	16.7	11.1	482	10.73
9,	32.2 to 1	"	14.2	10.1	443	10.76
26,	37.0 to 1	Lehigh,	10.2	12.7	380	10.70
28,	26.5 to 1	White Ash,	10.1	12.9	455	9.75
44,	26.6 to 1	– –	12.0	7.9	474	9.87
62,	47.4 to 1	Philadelphia and Reading,	10.7	11.9	428	10.60
Average,	33.9 to 1		12.3	11.1	444	10.40

TABLE No. 4. — *Anthracite Coal, Low Flue Temperature.*

18,	34.6 to 1	Lehigh,	9.4	14.0	349	11.24
19,	33.5 to 1	"	13.6	4.7	298	11.21
21,	37.6 to 1	"	13.2	8.6	344	11.53
26,	37.0 to 1	"	10.2	12.7	380	10.70
46,	44.2 to 1	White Ash,	15.7	9.4	369	10.61
63,	57.9 to 1	Philadelphia and Reading,	10.3	11.9	321	11.33
Average,	40.8 to 1		12.1	10.2	343	11.10

A similar comparison may be made on horizontal tubular boilers using Cumberland coal. Table No. 5 gives a list of these tests.

TABLE No. 5.

Common Horizontal Tubular Boilers, Cumberland Coal.

Number of Boiler.	Ratio of Heating Surface to Grate.	Percentage of Ash.	Coal per hour per square foot of Grate.	Temperature of Escaping Gases.	Water per lb. of combustible from and at 212 degrees.
			Lbs.	Degrees.	Lbs.
9, . . .	32.2 to 1	11.1	10.1	435	11.52
18, . . .	34.6 to 1	6.6	18.2	453	11.17
23, . . .	42.0 to 1	6.6	14.0	381	11.37
26 av., . .	37.0 to 1	6.5	9.3	360	11.43
34, . . .	29.4 to 1	8.7	10.9	530	10.60
55, . . .	41.6 to 1	6.6	7.0	431	12.07
56, . . .	40.0 to 1	6.5	11.1	408	11.98
62, . . .	47.4 to 1	8.3	6.7	340	11.24
63, . . .	57.9 to 1	8.3	12.1	397	11.99
74, . . .	53.1 to 1	7.5	13.6	413	12.47
Average, .	41.6 to 1	7.7	11.3	415	11.59

Here the average flue temperature is 415 degrees. Nos. 9, 18, 34 and 55 have temperatures exceeding 415 degrees. The average of these is 450 degrees, and the average evaporation is 11.34 pounds. The remaining boilers have temperatures below 415 degrees, the average of which is 383 degrees, and these give an average evaporation of 11.75 pounds. With 67 degrees less temperature of the escaping gases, the evaporation is higher by about 4 per cent. The difference here is less marked than in the anthracite tests, both in range of temperature and in economy, but it is in the same direction; that is, the highest evaporation is produced where the waste at the flue is the least.

The wasteful effect of a high flue temperature is exhibited by other boilers than those of the horizontal tubular class. This source of waste was shown to be the main cause of the low

economy produced in those vertical boilers which are deficient in heating surface. Examples of the same effect are numerous in the case of nearly every type of boiler treated in the paper. The cast-iron sectional boilers Nos. 1 and 72 have flue temperatures of 575 degrees and 462 degrees, respectively, and evaporate at the low rate of 9.79 pounds and 9.61 pounds of water from and at 212 degrees per pound of combustible. The six water-tube boilers, referred to below, are likewise wasteful on account of the high temperature of the escaping gases. The temperatures range between 452 degrees and 540 degrees, and the evaporations between 9.68 pounds and 10.36 pounds for anthracite coal, and between 10.79 pounds and 10.98 pounds for bituminous coal, all of which are low results for their respective grades of coal.

Number of Boiler.	Kind of Coal.	Temperature of Escaping Gases.	Water per lb. of combustible from and at 212 degrees.
		Degrees.	Lbs.
38, ...	Anthracite, ...	540	9.68
57, ...	Cumberland, ...	452	10.79
65, ...	Anthracite, ...	513	10.31
67, ...	"	428	10.36
71, ...	Cambria Bituminous, .	471	10.93
76, ...	Cumberland, ...	523	10.98

The plain cylinder boilers Nos. 40, 54 and 69 have a flue temperature, in the most favorable case, of 567 degrees, and an evaporation of only 9.22 pounds of water from and at 212 degrees per pound of combustible, and the evaporation is reduced as the waste temperature increases. The Galloway boiler No. 70, under extremely favorable circumstances as to kind of fuel, mode of firing and general management, gave an evaporation of only 11.06 pounds, this low result being due, evidently, to the fact that the temperature of the escaping gases was at the high figure of 575 degrees.

With this accumulation of examples, no other conclusion can be drawn than that one of the vital principles underlying the attainment of economy in the generation of steam, is a low temperature of the escaping gases. What the temperature should be to secure the best results is to some extent uncertain. In the examples of horizontal tubular boilers cited, the best average results where anthracite coal is used are secured with an average temperature of 343 degrees, and when Cumberland coal is used where the average is 383 degrees. It will not be far out of the way if we consider 375 degrees as a proper limit for anthracite coal, and 415 degrees for Cumberland coal. These are named for the general case. Individual boilers may, in rare instances, give excellent economy where the waste temperature exceeds these figures, and there are two or three examples furnished in the paper where this is true. There are so many instances referred to where a boiler secures a low grade of economy with more than 375 degrees in the flue when anthracite coal is used, and more than 415 degrees when Cumberland coal is used, not only among boilers of the horizontal tubular type, but among those of all other types, that it seems reasonable to lay down these temperatures for a limit.

Let us consider now what other conditions are necessary to secure economy. It cannot be denied that the relation between the heating surface and grate surface is important, and the question arises as to what that relation should be to obtain the highest efficiency. A proper settlement of this question cannot be made on the basis of the data given by the tests. An insufficient number of examples is furnished for a full examination. Much may be learned, however, from the few cases given. Keeping to the common horizontal boiler, let us select from the anthracite coal tests the boilers in which the ratio is below 40 to 1 and above 30 to 1, and compare with those in which the ratio is more than 40 to 1, taking, however, only those cases where the temperature of the gases is low and the rate of combustion is above 9 pounds per square foot of grate per hour. The tests used are Nos. 18, 21 and 26 for the small

ratios, and Nos. 23, 46 and 63 for the large ratios, and the averages of the two sets are as follows: —

Ratio of Heating Surface to Grate Surface.	Water per lb. of combustible from and at 212 degrees.
	Lbs.
36.4 to 1	11.16
42.0 to 1	11.05

There is a difference here of 11.6 in the ratio given, and only a slight difference in the character of the results. Nothing seems to be gained in these cases by increasing the surface above a ratio of 36.4 to 1, although this increase amounts to about one-third. There is in reality a loss. Carrying the inquiry farther, and taking the so-called double-deck boilers, of which there are four instances given in Table No. 1, the average ratio is 65.3 to 1 and the average evaporation is 10.88 pounds. Here also a loss of even greater amount is produced, although the surface is increased to the enormous extent of 80 per cent. These comparisons are made with different kinds of anthracite coals of large sizes, and some allowance must be made for the possible effect which a variation of quality of fuel may have on the results. But the comparisons are suggestive.

The evidence here given shows that a ratio of 36 to 1 provides a sufficient quantity of heating surface to secure the full efficiency of anthracite coal where the rate of combustion is not more than 12 pounds per square foot of grate per hour.

There are no satisfactory tests which can be averaged in the examination of this matter in cases where bituminous coal is used; but individual examples furnish valuable evidence as to the quantity of surface required. Boilers Nos. 51 and 52 are cases in point. Here an increase in the ratio from 36.8 to 42.8 secured a small improvement in the evaporation per pound of coal, and a high temperature of the escaping gases indicates that a still further increase would be beneficial. Among the

high results produced on common horizontal tubular boilers using bituminous coal, the highest occurs in No. 74, where the ratio is 53.1 to 1. This boiler gave an evaporation of 12.47 pounds. Passing to the double-deck form of boiler, No. 6 furnishes another example of high performance, an evaporation of 12.42 pounds having been obtained with bituminous coal, and in this case the ratio is 65 to 1. These examples indicate that a much larger amount of heating surface is required for obtaining the full efficiency of bituminous coal than for boilers using anthracite coal. There is sufficient reason for this requirement in the fact that bituminous coal is of a gaseous nature, and the heat generated in its combustion is spread through a larger space. The temperature of the escaping gases in the same boiler is invariably higher when bituminous coal is used than when anthracite coal is used, and this points to the same characteristic. In practice, the deposit of soot on the surfaces when bituminous coal is used interferes with the full efficiency of the surface, and an increased area is demanded as an offset to the loss which this deposit occasions.

It would seem, then, that if a ratio of 36 to 1 is sufficient for anthracite coal, from 45 to 50 should be provided when bituminous coal is burned, especially in cases like those referred to, where the rate of combustion is above 10 or 12 pounds per square foot of grate per hour.

The tests furnish some light upon the question as to the best manner of arranging the heating surface. This subject has special bearing upon the horizontal tubular type of boilers. In studying these boilers the question comes, what is the most efficient size of shell, and what number, length and diameter of tubes gives the highest result.

The size of shell does not appear to have much effect on the economy. The best result obtained with anthracite coal, viz., 11.53 pounds of water from and at 212 degrees per pound of combustible, is a case where the diameter of the shell is 48 inches, and this result is all that can be expected or desired from any size of boiler.

The number of tubes controls the ratio between the area of

grate surface and area of tube opening. Boilers Nos. 6 and 16 have a very large number of tubes and consequently a small ratio of grate to tube opening. The ratio is 5.2 to 1. They also have the very large area of heating surface represented by ratios of 65 and 60 to 1. Notwithstanding the ample provision of surface and other favorable conditions, the evaporation with anthracite coal is no higher than boilers give which have surface of much less extent, though of such character that the tube opening bears a smaller proportion to the grate surface. The conclusion which is well warranted by this fact is that a certain minimum amount of tube opening is required for efficient work. This conclusion is borne out by the result of the tests with anthracite coal on boiler No. 23, where the products of combustion make two circuits through the shell and the ratio of grate surface to tube opening is 11.6 to 1. The ratio of heating surface to grate here is 42 to 1, and the average evaporation per pound of combustible from and at 212 degrees is 11.16 pounds. The best results obtained with anthracite coal in the common horizontal boiler are in cases where the ratio is larger than 9 to 1. From these facts the conclusion is drawn that the highest efficiency with anthracite coal is obtained when the tube opening is from one-ninth to one-tenth of the grate surface.

When bituminous coal is burned the requirements appear to be different. We may again refer to the evidence of the tests. The effect of a large tube opening does not seem to make the extra tubes so inefficient when bituminous coal is used. The highest result on any boiler of the horizontal tubular class, fired with bituminous coal, is obtained when the tube opening is largest. This is boiler No. 74, which gives an evaporation of 12.47 pounds, and the ratio of grate surface to tube opening is 5.4 to 1. The next highest result is produced in boiler No. 6 already alluded to, which gives 12.42 pounds, and the ratio is 5.2 to 1. Another high result is produced by boiler No. 11. This is 12.03 pounds, and the ratio is 4.1 to 1. Table No. 5 gives three high results, averaging 12.01 pounds, and here the average ratio is 7.1 to 1. These instances are sufficient to

exhibit the need of a larger area of tube opening when bituminous coal is used than when anthracite is used, and this might be expected in view of the gaseous nature of the products of combustion. Without going to extremes, the ratio evidently most to be desired when bituminous coal is used is that which gives a tube opening having an area of from one-sixth to one-seventh of the grate surface.

As to the effect which size of tubes has upon economy, there is little direct information. Only one set of tests bears on the question, those made on boilers Nos. 51 and 52, in one of which 140 3-inch tubes are used, and in the other 100 3½-inch. The boiler with the smaller tubes gave the best result, but the improved performance was evidently due to the increased heating surface, of which there was an addition of one-sixth, rather than to any difference in the diameter of the tubes. It may be inferred from the fact that bituminous coal requires a larger collective area of tubes for best results than anthracite coal, that it may also require a larger individual area, and therefore larger diameter of tubes. This inference is not borne out by a comparison of the tests on boilers No. 6 and No. 74, one of which had 3-inch tubes and one 3½-inch, though the two boilers are of somewhat different type. A practical objection to the use of too small tubes must be kept in mind in those cases where a very smoky grade of bituminous coal is used, and frequent opportunity cannot be had to clean the tubes, so as to prevent a serious accumulation of soot.

The proper arrangement of tubes in the matter of length is settled when the relations of heating surface to grate and of grate to tube area are once fixed upon.

The best proportions of vertical tubular boilers are not established. There does not appear to be any reason why the relations of heating surface to grate and of grate to tube area, found desirable in the horizontal boiler, should not apply with equal force to the vertical boiler, and this view of the matter is justified by the results of the test on boiler No. 73. In this boiler there are 44.5 square feet of water-heating surface to 1 of grate, and 7.1 square feet of grate to 1 of tube area,

which agree practically with the proportions named for the best work in horizontal boilers using bituminous coal. If we allow the equivalent evaporation for the effect of the 18 degrees of superheating in the same manner as in the tests on the vertical boilers, considered under a previous heading, the evaporation into saturated steam containing one per cent. of moisture from and at 212 degrees per pound of combustible in this case is 12.75 pounds.

This discussion of the general conditions which secure economy applies to medium rates of combustion of say 10 to 12 pounds per square foot of grate per hour, such as will secure the rated capacity of the boiler when the power is based on 12 square feet of water-heating surface per horse-power.

3. Comparison of Different Kinds of Boilers.

It seems to the writer that the general principles of economy, to which attention has just been devoted, though deduced mainly from a study of horizontal tubular boilers, are based upon such reasonable grounds that they may be applied to all forms of steam boilers. The proportion most to be desired between tube opening and grate surface cannot be applied to a boiler which has no tubes; but the relations established between heating surface and grate surface, and the best condition as to the temperature of the escaping gases, are principles which can be applied in all cases. Before making a comparison of the economy of different types of boilers, these principles should be remembered, and the comparison based on the performance of the boiler when suitable conditions exist for the attainment of the best result. There is only one case where this cannot be done, and that is where the construction of the boiler forbids the attainment of those conditions.

A large proportion of the boilers treated of in the paper are in one form or another of the horizontal tubular type. The number of these is 47. Of this number, there are 32 of the common return tubular type; 1 is what may be termed a direct tubular with common furnace; 2 are direct tubular with detached furnace; 1 has two furnaces for alternate firing;

2 are provided with a water leg for the front of the furnace; 3 have such an arrangement of tubes that there is a double passage of the products of combustion through the boiler; 6 are of the double-deck type.

Of the remaining boilers, 3 are plain cylinder, 12 vertical tubular, 3 cast-iron sectional, 11 water-tube and 1 Galloway.

The most favorable results with the common horizontal boiler are those obtained on Nos. 19 and 21 with anthracite coal, and on Nos. 55, 56 and 74 with Cumberland coal. The average of the first is 11.37 pounds and of the second 12.17 pounds. The conditions in all these cases were favorable.

The direct tubular boiler with common furnace, No. 25, cannot be compared with these on account of the different kinds of coal used; but this boiler can be compared with No. 24, which is of the common type and which used the same kind of fuel. In this comparison it stands at a disadvantage, but there seems to be a reason for it in the fact of the unfavorable proportion of heating surface to grate, which is only 27.7 to 1.

The direct tubular boilers with detached furnace, Nos. 17 and 63, cannot both be brought into the comparison, since the former used a mixture of screenings and bituminous coal. The latter, No. 63, which was tested with both anthracite and Cumberland coal can be used. The anthracite coal gave an evaporation of 11.33 pounds, and the bituminous coal 11.99 pounds. Both of these are nearly as good results as the high-grade common boilers produced. Here the heating surface bears a ratio of 57.9 to 1 of grate, and the ratio of grate to tube opening is 6.7 to 1. Under these circumstances, which are most favorable, a high result would be expected from any form of boiler, and the detached furnace cannot reasonably lay claim to any special advantage.

The boiler with two furnaces for alternate firing, No. 33, which is evidently of use only in cases where bituminous coal is burned, gave a result much below that of the common boiler. There is plenty of heating surface, but it was for some reason inefficient, for a large waste occurred, as indicated by the high temperature of the escaping gases. The difference

between the evaporation obtained, which was 10.93 pounds, and the standard of reference, 12.17 pounds, is due in a measure to this disadvantage, but the difference is too large to be wholly accounted for by the waste at the flue. It must be concluded from this single instance that the double furnace type of boilers is inferior to the common type.

The boilers which have a water leg for the front of the furnace, differ so little from the common boiler that neither loss nor gain, if either occurred, could with reason be attributed to this method of construction. Boiler No. 18, which is fitted in this manner, gave an evaporation with anthracite coal amounting to 11.24 pounds. This excellent result is largely due, no doubt, to the new condition of the boiler and to the favorable proportions which existed.

The boilers in which a double passage of the products of combustion occurred are Nos. 7, 23 and 66. Only one needs to be considered, viz., No. 23, the others being foreign to the discussion. Here, again, a favorable result is produced with anthracite coal, the evaporation being 11.20 pounds of water from and at 212 degrees per pound of combustible, and here, again, favorable conditions lent their aid. The result obtained with bituminous coal is rather low. According to the conclusions which we have established relating to proportions of boilers, the tube opening is insufficient, being only a little more than one-half of that laid down for bituminous coal. This form of boiler is not well adapted for securing a large tube opening, because with a given number of tubes only half of them can be employed for carrying the products in one direction. The desired end must be secured by reducing the length of the tubes and increasing their number, using a larger shell. The test gives no indication of the result which would follow this change of construction.

The double-deck boilers Nos. 6, 16 and 42, burning anthracite coal with high rates of combustion, give an average evaporation of 11.05 pounds. Those numbered 6 and 11, burning bituminous coal, give an average of 12.22 pounds. One is slightly below the standard of the common tubular boiler and

the other slightly above it. Here the benefit is one due undoubtedly to favorable proportions, and this benefit can be fully attained by the adoption of similar proportions in the common type of boiler, as individual tests clearly show.

With all the various modifications in the type of horizontal tubular boiler to which the tests refer, some of which it must be admitted give excellent results, there is no other conclusion to be drawn than that the form of horizontal boiler, which with suitable proportions and operation can be depended upon to give the highest evaporation, is the common horizontal return tubular boiler, so widely used in New England factories.

Passing to the boilers of the other types named, the first is the plain cylinder. Little need be said of this boiler, it is of such evident inferiority as an economical generator of steam. The ratio of heating surface to grate surface is in no case above 10.9 to 1. If 36 square feet of heating surface is required for economical results, nothing can be expected from a proportion of less than one-third of this quantity, and it is probably out of the question to institute a rearrangement which will secure the desired end in any practical way.

The next form is the vertical boiler. This has already been taken up under the head of superheating boilers, and only the conclusions there derived require mention. These are, that if suitable attention is given to the design of the boiler, the vertical tubular compares favorably with the horizontal boiler. The example afforded by boiler No. 73, using Cumberland coal, corroborates this view in the most positive manner. The result obtained in this one case, when reduced to the basis of horizontal boilers giving steam containing one per cent. of moisture, in the manner pointed out for superheating boilers, is an equivalent evaporation of 12.75 pounds of water from and at 212 degrees per pound of combustible. We have a result here which surpasses any given by horizontal tubular boilers. Its accuracy cannot be questioned since vertical boiler No. 47, though of a little different arrangement, gave a result which, without allowance for superheating, is precisely the same. These instances are not of sufficient number to establish the

vertical boiler as one of superior economy to the horizontal boiler, but they show that when properly designed, it is at least the equal of the horizontal boiler.

The three cases of cast-iron sectional boilers, viz., Nos. 1, 41 and 72, give comparatively poor results. The unfavorable showing is due in some degree to unfavorable conditions. In every one the ratio of heating surface to grate surface is below that which has been given as essential to economical work. In all three cases the effect of the departure from correct principles is seen in the high degree of flue temperature. There is nothing in the construction of the boiler to prevent the employment of any proportions between heating surface and grate surface which may be desired, and it is not improbable that the results would have been equal to those of the tubular boiler if suitable proportions had existed.

There is some variety in the economic results produced by the water-tube boilers. Out of the whole number of boilers given, amounting in all to eleven, only two appear to reach the standard laid down for good economy. The principal results are given in Table No. 6.

Examining these figures closely, it is seen that the two results referred to (boilers Nos. 35 and 75) were produced by boilers having a large ratio of heating surface to grate surface, and in which there was a high rate of combustion and a low temperature of the flue. In addition to this, the boilers were comparatively new. These are conditions which, as already shown, invariably attend high performance. Both results compare favorably with the standard of tubular boilers, and one — that given by boiler No. 75 — surpasses the best figure given, not only for horizontal tubular boilers, but for all other kinds referred to in the paper. The remarkable performance here shown, however, is but an individual case of excellent work. It is unsupported by any other result, and for this reason some doubt may be entertained whether the water-tube type of boiler can be depended upon for the superior work which this exemplifies. Nos. 57, 71, 76 and 77, which used high grades of bituminous coal, give a much lower

TABLE No. 6. — *Water-Tube Boilers.*

Number of Boiler.	Ratio of Heating Surface to Grate.	Kind of Coal.	Percentage of Ash.	Coal per hour per square foot of Grate.	Temperature of Escaping Gases.	Water per lb. of combustible from and at 212 degrees.
				Lbs.	Degrees.	Lbs.
32, ...	37.3 to 1	Lehigh Chestnut, ...	14.0	9.3	337	10.61
35, ...	40.0 to 1	Shamokin Pea, ...	16.6	14.0	371	11.26
38, ...	40.3 to 1	Lehigh Broken, ...	9.2	17.8	540	9.68
48, ...	36.5 to 1	Lehigh Chestnut, No. 2, . .	14.7	8.2	360	10.00
57, ...	62.5 to 1	George's Creek Cumberland, .	7.7	16.8	452	10.79
65, ...	24.7 to 1	Lackawanna Egg, ...	11.4	14.5	513	10.31
67, ...	31.4 to 1	Lackawanna Chestnut, No. 2, .	16.4	10.9	428	10.36
71, ...	45.5 to 1	Cambria, ...	10.5	16.9	471	10.93
75, ...	44.7 to 1	Four parts Powelton, one part Screenings, ...	8.8	17.5	402	13.01
76, ...	48.4 to 1	George's Creek Cumberland, .	6.4	16.3	523	10.98
77, ...	50.5 to 1	Cumberland, ...	6.3	12.0	398*	10.73

* Owing to cold air leakage into flue, this is probably too low.

result, and after the most favorable allowance is made for the waste due to excessive flue temperature, they do not appear to be capable of obtaining more than 12 pounds evaporation, which is much below the performance of No. 75. The same boiler (No. 75), using a high grade of coal on another occasion three years later, gave a result 17 per cent. below the figure named. This is boiler No. 57. A smaller grate was used on that occasion, and the proportion of heating surface to grate was thereby increased, still preserving about the same rate of combustion. The inferior results given for the remaining water-tube boilers can generally be attributed to waste heat at the flue. In boilers 65 and 67 the high temperature seems to be due to a deficiency in the quantity of heating surface. In the remaining boilers, it appears to be inefficiency of the surface which causes loss, and this may be attributed either to deposit of scale on the interior of the surface, or of soot and kindred substances on the exterior. The last may be of frequent occurrence if the care of the boiler is neglected, more especially since the exterior surfaces of water-tube boilers are difficult of access, and are usually cleaned only by the use of a jet of steam. On the whole, the water-tube boilers may be considered to be equal in economy to the tubular boilers, under the conditions of comparison determined upon, that is, when the conditions are favorable to economy.

There remains the single Galloway boiler, which was tested with Cumberland coal. Unfavorable conditions for economy exist here, and the low result produced is no different from what would be expected. According to the principles governing economical work many times exemplified in this discussion, there were disadvantages on every hand, and the results furnish no guide as to the capabilities of this form of boiler when operated under favorable conditions.

The general conclusion to be drawn from all these comparisons is that the economy with which different types of boilers operate depends much more upon their proportions and the conditions under which they work, than upon their type; and, moreover, that when these proportions are suitably carried

out, and when the conditions are favorable, the various types of boilers give substantially the same economic result.

4. Comparison of Different Kinds of Fuel.

There are two methods of treating the question of a comparison of different kinds of fuel.

One method determines the relative economy of the various fuels when each is burned under the conditions regarding type and arrangement of boiler, which will give the most favorable results. The other method compares the various results obtained when the fuels are burned in the same boiler, regardless of proportions and regardless of the special adaptability of the boiler for the economical use of any particular kind of fuel. The true economy of a fuel depends to some extent upon its market price. Changes which occur from time to time in the relative market prices of different fuels make one fuel the most economical at one time and another fuel at another time. It becomes advisable, on this account, to change fuels when a sufficient change of prices occurs. If this is done it is not usually practicable to make any material alteration in the boiler, and as a consequence one design of boiler must answer for all kinds of coal. It is for this reason that the second method alluded to for the treatment of this subject is preferred, and this is the one to which most of the tests conform.

A comparison will be made first on the basis of the number of pounds of water from and at 212 degrees evaporated per pound of coal. Anthracite broken coal will be used as a standard, and the comparison made by determining the percentage of increase or decrease in each case above or below the evaporation with that coal. Table No. 7 gives a summary of the results of those tests which can be treated in this manner.

TABLE No. 7.

Number Designating Test.	Cumberland (increase).	Chestnut (decrease).	Pea (decrease).	Pea and Dust and Cumberland (decrease).	Pea and Dust and Culm (decrease).	Nova Scotia Culm (decrease).
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
10, ...	20	–	–	–	–	–
12, ...	–	–	–	–	2	–
14, ...	17	–	–	–	–	–
15, ...	–	–	–	–	–	7
16, ...	10	–	–	–	–	–
18, ...	–	–	–	14	–	–
19, ...	–	–	–	–	–	21
46, ...	7	–	–	–	–	–
47, ...	–	–	–	6	–	–
54, ...	–	4	–	–	–	–
55, ...	–	–	13	–	–	–
57, ...	14	–	–	–	–	–
58, ...	–	–	–	*2	–	–
69, ...	–	–	6	–	–	–
70, ...	–	–	–	–	14	–
73, ...	17	–	–	–	–	–
75, ...	–	–	–	4	–	–
119, ...	9	–	–	–	–	–
122, ...	8	–	–	–	–	–
123, ...	–	–	–	*1	–	–
Average, . .	12.8	4	9.5	4.2	8	14

* Increase.

If we assume an evaporation of 11.00 pounds of water from and at 212 degrees per pound of combustible for the performance of anthracite broken coal, which seems to be a result within easy reach in good practice, and farther assume 11 per cent. for an average percentage of ash in such coal, the above comparison will be applied to an evaporation of 9.79 pounds of water from and at 212 degrees per pound of coal. The performance of the various fuels, expressed in pounds of water evaporated per pound of dry coal, will then be as follows: —

Name of Coal.	Water from and at 212 degrees per lb. of dry coal.
	Lbs.
Anthracite Broken,	9.79
Cumberland,	11.04
Anthracite Chestnut,	9.40
Anthracite Pea,	8.86
Two parts Pea and Dust and one part Cumberland,	9.38
Two parts Pea and Dust and one part Culm,	9.01
Nova Scotia Culm,	8.42

These figures apply to dry coal. The fine grades of anthracite coal and the bituminous coals are frequently moist from exposure to the weather. In the moist or even wet condition which exists when the purchaser buys coal, this comparison does not indicate the true relative performance. The quantity of moisture which such coal contains is uncertain and variable. Three per cent. may be allowed for an average, but in individual cases it may run anywhere from 0 to 6 per cent. or 8 per cent. While this allowance serves to reduce the evaporation with the coals named, the coarse grades of anthracite coal in practice have an allowance which, though of different nature, operates in the same manner. The figures of the tests are based on the weight of coal obtained by deducting unconsumed fuel left at the end of the test, and no deduction of much consequence requires to be made except when the large grades of anthracite coal are used. In the practical work of operating boilers much of this unconsumed coal is thrown away with the ashes. It readily amounts to 3 per cent., and this corresponds to the allowance which with other fuels may be made for moisture. The quantities given may therefore be used, as they stand, for purposes of comparison, although taken individually they do not show precisely the work of the various fuels in the conditions in which they are bought and used.

In the comparison of relative quantity of water evaporated by the different fuels, it is seen that Cumberland coal easily takes the lead. As Table No. 7 shows, the evaporation is 12.8

per cent. more than that of anthracite coal. In the other cases the evaporation is less than that of anthracite coal; chestnut coal is 4 per cent. less; pea coal 9.5 per cent.; mixture of pea and dust and Cumberland 4.2 per cent.; mixture of pea and dust and culm 8 per cent.; Nova Scotia culm 14 per cent.

Proceeding farther, let us examine the subject from the financial standpoint and make a comparison on the basis of cost. Two elements must be considered here, viz., cost of fuel and cost of labor. Both vary for the different fuels. Take the case of a plant of 1,000 horse-power. According to the standard of horse-power used in the paper, the daily product of steam for ten hours' run of such a plant is 344,721 pounds, assumed to be evaporated from and at 212 degrees. Using this figure, the number of tons of the various kinds of coal used per day is computed and the quantities are given in Table No. 8. This table also contains the prices of the various coals found by taking an average of the present quotations for a cargo delivered in the cities of Lawrence, Fall River and Waltham; and farther, the total cost of coal for one day's run at the prices named. The table also gives the cost of labor required in firing, the assumption being made in the case of anthracite coal of broken, chestnut or pea sizes, that the labor is performed by two day firemen, one night fireman and two helpers, and in the case of bituminous coals that one additional fireman is required; while in that of the mixed fuels, one fireman and one helper additional are required. The wages of the firemen are assumed to be $1.75 per day, and of helpers $1.25 per day. Finally, the table gives the total cost of fuel and labor for the day's run of ten hours, computed in accordance with the assumptions named.

It appears from Table No. 8 that at the prices named there is a difference in the cost of coal and labor for a day's run on a 1,000 horse-power plant, reckoned between the highest and lowest quantities, of $41.27. The significance of this sum is apparent when it is considered that in a year's time it represents $12,711. Such a sum has no small relation to the total amount of profit which a mill employing a 1,000 horse-power plant realizes.

TABLE No. 8. — *Cost of Coal and Labor for a Day's Run of Ten Hours, 1,000 Horse-power Plant.*

	Anthracite Broken.	Cumberland.	Anthracite Chestnut.	Anthracite Pea.	Two parts Pea and Dust and one part Cumberland.	Two parts Pea and Dust and one part Culm.	Nova Scotia Culm.
Weight of coal used in ten hours (2,240 lbs. = 1 ton), ... tons	15.7	13.9	16.4	17.4	16.4	17.1	18.3
Cost of coal per ton of 2,240 lbs., . . . $	5.65	4.56	6.13	3.75	3.72*	3.29	3.28
Cost of coal used in ten hours, ... $	88.70	63.38	100.53	65.25	61.05	56.26	60.02
Cost of labor per day, ... $	7.75	9.50	7.75	7.75	10.75	10.75	9.50
Total cost of coal and labor per day, . $	96.45	72.88	108.28	73.00	71.80	67.01	69.52

* Price of pea and dust $3.30 per ton.

This sum saved would be sufficient to add one per cent. and possibly two per cent. to the annual dividends.

The highest cost in the comparison attends the use of anthracite chestnut coal, and the lowest that of a mixture of two parts pea and dust and one part Nova Scotia culm. The pure Nova Scotia culm stands about on a par with the mixture.

If the Nova Scotia coal and the mixture containing Nova Scotia coal are left out of the comparison, the mixture of pea and dust and Cumberland coal takes the lead as the cheapest fuel, and the Cumberland follows closely upon it. These figures show that at prices which now hold, little is gained by the use of a mixture of either pea and dust and Cumberland or of pea and dust and culm. Either of the bituminous coals fired without mixture produces nearly as good results. Considering the fact that the use of the mixed fuel reduces the available power of the boiler, the pure coal easily has the advantage; no one would go to the trouble of using an inferior grade of coal, such as the best pea and dust mixed with bituminous coal is, and such as much of it is liable to be, unless by so doing a material reduction in cost could be attained. If yard screenings can be delivered at $2.75 per ton, and if it secures the same result as pea and dust coal, the total cost of fuel and labor when a mixture of two parts screenings and one part Cumberland coal is used amounts to $65.69 per day, and this sum is lower than any quantity given in the table.

Pea coal comes next to Cumberland in the order of cheapness, and then the anthracite broken. The pea coal differs but a trifle in total cost from that of Cumberland coal.

An important matter relating to the use of different kinds of coal is the relative amount of power which they give when fired in the same boiler. Boiler No. 9, rated at 54 horse-power (on the basis of 12 square feet of heating surface), gave 60 horse-power with Cumberland coal, 53.9 horse-power with anthracite broken, and 38.5 horse-power with a mixture of two parts pea and dust and one part Cumberland, the damper being wide open in every case. Boiler No. 18, rated at 74 horse-power with $\frac{3}{8}$-inch draught suction, gave 143.8 horse-power

with Cumberland coal, 105.5 horse-power with anthracite egg, and 95.1 horse-power with a mixture of equal parts of screenings and Cumberland coal. Boiler No. 23, rated at 87 horse-power, gave 84 horse-power with anthracite broken coal, 105.4 horse-power with Cumberland, and 82.2 horse-power with a mixture of two parts screenings and one part Cumberland. The draught was 0.28 inches. Boiler No. 28, rated at 129 horse-power, gave 192.3 horse-power with anthracite broken coal, draught 0.11 inches; 149.2 horse-power with pea coal, draught 0.12 inches; and 157.1 horse-power with 44 parts pea and dust and 37 parts culm, draught 0.28 inches. Vertical boiler No. 30, rated at 140 horse-power, gave 94 horse-power with Cumberland coal, draught 0.07 inches; 103.8 horse-power with anthracite broken, draught 0.05 inches; and 118.1 horse-power with two parts screenings and one part Cumberland, draught 0.32 inches. Boiler No. 63, rated at 270 horse-power, gave 196.1 horse-power with anthracite broken coal, draught 0.25 inches; 214.6 horse-power with Cumberland coal, draught 0.20 inches; and 204.8 horse-power with 6 parts screenings and 4 parts Cumberland, draught 0.31 inches. It is seen, therefore, that as regards capacity, Cumberland coal secures the largest power with a given draught, and pea coal or mixtures of screenings and bituminous coal the least. This suggests that to secure the same capacity from a given boiler with different kinds of coal, the area of grate surface must be varied to suit the varied kinds of coal. In the case of boiler No. 18, for example, the grate would have been increased in the proportion of 95.1 to 143.8 when the mixed fuel was used, in order to bring the amount of power developed up to that obtained with Cumberland coal.

Among the tests given in the paper are a few made with other kinds of fuel than those upon which the comparisons are made.

There are several with "chestnut No. 2" anthracite, which corresponds in size to the pea grade. The evaporation and the cost also are about the same as with pea coal.

Two tests are given where coal from the neighborhood of

Pittsburgh was used. These were made on boilers Nos. 61 and 68, and the conclusion drawn from the results is, that this coal under favorable circumstances, gives about the same evaporation per pound of fuel as anthracite broken coal.

From the indication of a single test, made on boiler No. 64, the performance of Ohio lump coal with favorable conditions appears to fall about 5 per cent. below the economy of anthracite broken coal.

Two tests are given which show the performance of coke, that is, the refuse coke of gas retorts used in the manufacture of illuminating gas. Test No. 105, made with coke on a plain cylinder boiler, gave 8 per cent. less evaporation per pound of fuel than anthracite pea. Test No. 108, made with coke on a horizontal tubular boiler, gave 14.7 per cent. less evaporation per pound of fuel than a high grade of Cumberland coal. The cost of the coke was $3.00 for 2,000 pounds.

Three tests give some information upon the use of petroleum for fuel. Test No. 38, made with petroleum, under somewhat unfavorable conditions, gave an evaporation of 11.96 pounds of water from and at 212 degrees per pound of petroleum. Test No. 124 with "residuum" of petroleum gave 13.66 pounds. A test with Canadian oil gave 15.00 pounds. Suppose the last figure can be realized in good practice. At this rate, the quantity of oil required to produce 1,000 horsepower for a day's run of ten hours (344,721 pounds from and at 212 degrees) is 22,981 pounds, or 3,536 gallons (1 gallon = 6.5 pounds). The price of oil per gallon, required to make the cost for a day's run equal to that of, say Cumberland coal, may be figured from Table No. 8. The total cost of fuel and labor here given for Cumberland coal (the price being $4.56 per ton) is $72.88. The cost of labor when oil is used is reduced to, say one man at $2.00 per day and a helper at $1.25, making a total of $3.25. Subtract this from $72.88 and there is left for the cost of fuel $69.63, which is $1\frac{97}{100}$ cents per gallon of petroleum, or 98.5 cents per barrel of 50 gallons. This means, in round numbers, that the price of oil must be less than one dollar per barrel, delivered at the boiler, in order

that the cost of fuel and labor for a 1,000 horse-power plant shall be equal to that which obtains when Cumberland coal is used at $4.56 per ton.

If the economic result with petroleum goes up to 18 pounds, the price of oil per barrel to equal Cumberland coal on this basis is $1.18 cents. It is to be noted that these figures are based upon a barrel of 50 gallons. If the barrel is taken to be 42 gallons, the prices become 82.7 cents for an evaporation of 15 pounds, and 99.1 cents for an evaporation of 18 pounds.

5. Miscellaneous.

The general subject of boiler economy has now been examined, so far as it is affected first, by the character of the steam, that is, as to its being saturated or superheated; second, by the general arrangement of the heating surface and the conditions under which the boiler is worked; third, by the type of the boiler; and fourth, by the character of the fuel burned. These may be regarded as the more noteworthy divisions of the subject. Incidental matters remain to be taken up, and these are quite as interesting, and sometimes almost as important, as the main questions thus far considered.

Boiler Setting.

One of the most prominent questions of an incidental nature connected with the economy of boilers is that of the effect which the form of the setting has, in cases where the boiler is set in brick-work. The tests furnish no pertinent data upon the effect of one feature in the matter, that is, the general shape of the setting. In horizontal tubular boilers, for example, nothing is given to show what distance there should be between the grate and the shell and between the top of the bridge wall and the shell. There is nothing to show in what manner the bridge wall should be arranged, whether curved upward to conform to the curve of the shell, or simply left flat, and whether the front of the wall should be inclined or vertical; neither is there any light upon the question of filling the space behind the bridge wall or leaving it open. It is significant, however, that

the highest results given by the various tests are in some cases obtained with one form of setting and in some with another form. Boiler No. 18, which gave a high result with anthracite coal, has a flat bridge wall with perpendicular front, and the space behind the bridge is partially filled. Boiler No. 19, which also gave a high result with anthracite coal, has a curved bridge wall with vertical front, and the space behind is filled so as to conform to the same curve. Boiler No. 23 is another case in point, and here the bridge wall is flat with a vertical front, and the space behind is filled in so as to provide an inclined bed leading down to a deep chamber at the rear end. Boiler No. 62, which gave a good result, if allowance is made for the high temperature of the gases, has a flat bridge wall with perpendicular front, and the space behind is filled to an even level with the top. Boilers Nos. 24 and 27, using inferior grades of anthracite coal, showed favorable results, and the bridge walls are flat with vertical fronts and the space in the rear is open in both cases. Passing to boilers using Cumberland coal, Nos. 55 and 56, which give high results, both have vertical walls; No. 55 is curved at the top, with open space behind, and No. 56 is flat with open space, the latter being provided with a second wall at the rear end of the boiler. It would appear from these examples that the general form of the setting in respect to the particulars named may be one thing or another, and the boiler still give the highest economy. This furnishes strong ground for the conclusion that the matter is of little importance, and that the plan to be followed is the one which will secure the simplest, and at the same time the most convenient arrangement.

Although the tests furnish no direct and positive information upon the feature relating to the shape of the setting, they give some very pointed indications regarding another feature of the matter, viz., the effect of admitting air into the furnace above the fire. Many settings are arranged with a view to this special object. A current of air in a finely divided state is introduced into the furnace so as to mingle with the products of combustion as they emerge from the burning coal.

The simplest method of doing this is to conduct the air directly from the outside to the interior of the bridge wall, which is made hollow, and to discharge it through perforations in the top covering of the wall, which may be either iron or brick. The air thus supplied mingles with the lower strata of burning gas as it skims over the bridge. Boiler No. 26 was arranged for an air supply according to this method, and tests Nos. 59 to 64 were conducted with a view to determining the effect which the admission of air has upon the economy of the boiler, three different kinds of coal being used. The coals were Cumberland, anthracite broken and a mixture of two parts pea and dust and one part Cumberland. The air was supplied through an opening having an area of 38.5 square inches, which is 1.4 square inches for one square foot of grate surface. When Cumberland coal was used the full opening of this area was employed; when either anthracite coal or the mixture was used the opening was contracted to about one-half, thus presenting an area of 0.7 square inches for one square foot of grate. There is a wide difference in the effect of admitting air in the different cases. In the case of Cumberland coal, the evaporation is increased 5.9 per cent. per pound of coal, and 6.2 per cent. per pound of combustible; that of anthracite coal is decreased one per cent. per pound of combustible and is about the same per pound of coal; that of the mixed fuel is decreased 2 per cent. per pound of coal and 4.7 per cent. per pound of combustible. The effect which the introduction of air had upon the appearance of the products of combustion, as viewed by an observer at the "peek hole" back of the bridge wall, was very noticeable in every case. It was greatest, to be sure, with Cumberland coal, but the heightened color and the increased activity of the flame produced by the entrance of air was plainly to be seen whichever fuel was used.

It is to be noted that an apparent benefit was realized in the case of both the anthracite coal and the mixed fuel when judged by the improved state of combustion which the eye beheld. In reality, however, there was a loss, and this goes to show that the occular method of judging in these matters is lia-

ble to be deceptive. It is feared that purchasers of boiler appliances, who are ignorant of these facts, have often been misled by the "peek hole" argument.

In these tests another effect was produced by the admission of air. The quantity and density of the smoke issuing from the chimney was reduced. This was most marked with Cumberland coal, which gave the most smoke. When air was excluded, smoke was visible $\frac{74}{100}$ of the time; when air was admitted, the smoke was visible $\frac{70}{100}$ of the time. In the case of the mixed fuel little smoke was produced in either case.

A second method of admitting air which, though not so simple, is rather more effective than that just named, is the one applied to boiler No. 18. Here the air is supplied first to a pipe laid in the bridge wall, and then to perforated cast-iron globes which rest upon the top of the wall. This method is rendered more effective than the first by the more thorough mixture which it secures between the incoming air and the burning gases. The quantity of air supplied is increased above that naturally drawn in by means of a jet of steam. The steam thus supplied mingles with the air. In this case the effect of admitting air above the fuel, when Cumberland coal was burned, was to increase the evaporation per pound of coal 8.4 per cent., and per pound of combustible 8 per cent. It may be added that a test made with Lehigh coal, not recorded, showed that with this fuel the admission of air was attended by an increase of evaporation of 1.9 per cent. per pound of coal and 3.7 per cent. per pound of combustible.

A third method of admitting air, which is more efficient than either of the first two, is that supplied to boiler No. 74. It consists in supplying one current of air through the bridge wall by means of perforations in the rear face of the wall near the top, and another current of air through a secondary wall placed a short distance to the rear of the bridge wall, and elevated so as to close up the passage between it and the shell of the boiler, and make the products of combustion descend and pass beneath it. The second current of air discharges through perforations in the front face of the hanging wall. By these provisions the

entering air is thoroughly diffused through the whole volume of burning gas. The only test made on this boiler was with the air admitted, and there is consequently no positive information as to the economy of this method. There is indirect evidence, however, pointing to its superiority, in the fact that the result of the test was most excellent, being 12.47 pounds of water from and at 212 degrees per pound of combustible, and this is the highest given in the paper for horizontal tubular boilers.

A fourth method consists in first passing the air back and forth through passages running lengthwise of the walls of the setting and then discharging it through perforations, part of which are located on the top of the bridge wall and part on the two sides of the furnace. The object sought is to supply the air in a somewhat heated condition. Several tests are given which show the effect of this method. Tests Nos. 20 and 21 were made for this purpose. A mixture of two parts pea and dust and one part Nova Scotia culm was used, and in one test air was supplied through the registers in the fire-doors, and in the other through the passages in the walls. The use of the air passages secured an increased evaporation of 2 per cent. per pound of coal, while the result, when figured on combustible, was the same in both cases. Vertical boiler No. 29 is provided with air passages running up and down in the circular wall of the setting, and discharging at numerous points over the fire, through perforations. Test No. 71, made on this boiler with air admitted, gave 4.3 per cent. less evaporation per pound of coal and 2.3 per cent. less per pound of combustible than test No. 72, made with air excluded. The fuel was a mixture of two parts anthracite screenings and one part Cumberland coal. Boiler No. 36, in which air was admitted in accordance with this method, compared with an exactly similar boiler (No. 37) in which air was not admitted, fired with a mixture of three parts pea and dust and one part Cumberland coal, gave 4.5 per cent. less evaporation per pound of coal and 4.7 per cent. less per pound of combustible. Boiler No. 50, with air admitted and fired with Nova Scotia coal, gave 1 per cent. higher evaporation per pound of coal and 1.5 per cent.

higher evaporation per pound of combustible than boiler No. 49, which was precisely similar, except that no provisions were made for admitting air through the walls. In both cases the registers in the fire-doors were open. These presented an open area of 22 square inches, or one-fourth of one square inch for one square foot of grate surface. The openings to the passages in the walls presented an area of 32 square inches, or about four-tenths of one square inch for one square foot of grate. This proportion is only about one-fourth of that provided in the case first noticed (boiler No. 26), where the admission of air to Cumberland coal gave about 6 per cent. advantage.

The conclusion drawn from these examples is that a considerable advantage attends the admission of air above the fuel when bituminous coal is employed, the amount of gain depending somewhat upon the method employed. There is no advantage in the system when mixtures of anthracite screenings and bituminous coal are used, if carried out according to either the first or fourth methods; and finally little or no benefit is derived when anthracite coal is burned.

Another question of an incidental nature connected with the general subject of boiler economy, is that of the economy produced by the employment of a feed-water heater in the flue, and the tests show that this may be of considerable importance. That the use of a flue heater, in connection with a boiler having too little heating surface, and sending a high degree of waste heat into the chimney, is productive of economy, no one can have good reason to doubt, and this is clearly shown by the results of tests Nos. 112 and 113, which are cases in point, where a temperature of 618 degrees existed, and the heater added 29 per cent. to the evaporation per pound of coal. The special interest in the question is not in cases like this, where the waste heat was due to defects in the design and operation of the boiler, but rather in cases of reasonably good practice, where the temperature of the flue is not what may be regarded as excessive. There are a number of such cases given, and the general results produced are repeated in Table No. 9.

TABLE No. 9. — *Tests with Flue Heaters.*

1.	Number of boiler, ...	41	57	59	60
2.	Area of heating surface, boiler, ... sq. ft.	5,592	3,126	4,058	1,894
3.	Area of heating surface, heater, ... sq. ft.	1,280	1,600	1,920	1,600
4.	Temperature of gases leaving boiler, ... deg.	403	435	361	376
5.	Temperature of gases leaving heater, ... deg.	299	279	254	231
6.	Temperature of feed-water entering heater, . . . deg.	111	84	79	95
7.	Temperature of feed-water entering boiler, . . . deg.	169	196	145	175
8.	Increased evaporation produced by heater, . . . %	9.3	12.8	7	10.5

The average results of these four trials show that the use of a flue heater having 44 per cent. as much heating surface as that of the boiler, applied where the temperature of the escaping gases is 394 degrees and the initial temperature of the feed-water 92 degrees, increases the evaporation per pound of coal 9.9 per cent. The important question which arises is, does this amount of gain pay for the addition to the plant involved by the employment of this apparatus? Let us refer the matter to a plant of 1,000 horse-power, and use for a calculation the cost of Cumberland coal required for a day's run of 10 hours, given in Table No. 8, which is $63.38. The saving produced by the flue heater is $5.71 per day, and this amount represents for a year of 308 days a total saving of $1,759. The cost of a heater with complete equipment of setting and appurtenances, having a surface of say 5,000 square feet, which corresponds to the instances referred to, is $7,000 to $8,000. The economy secured is, therefore, sufficient to pay a yearly return of from 20 per cent. to 25 per cent. on the additional investment, which is certainly of some importance.

It must be borne in mind that this result applies only to a case where the temperature of the water supplied to the heater is comparatively low, corresponding to that of the overflow

water of a condensing engine. On the other hand, it is a case where the temperature of the flue is not far from that laid down in another part of the paper for boilers giving most economical results, and it is seen from the many instances recorded that the exigencies of boiler work often bring about a much higher flue temperature. The flue heater thus has a useful place, not only in a few instances but in a large majority of boiler plants where the water is supplied in a comparatively cold state. In the cases given, there is a reduction of 128 degrees in the temperature of the gases, and an increase of 79 degrees in the temperature of the water. Each one per cent. added to the evaporation corresponds to a reduction of about 13 degrees in the temperature of the escaping gases.

It is important to note the effect which the use of the heater has upon the draught. The amount of draught suction which existed in some of the above examples and in one additional example, together with information regarding quantity of coal burned and other matters bearing on the question, is given in Table No. 10.

The effect of a reduced temperature of the escaping gases, which always accompanies the employment of the heater, is seen in every one of these instances, to reduce the draught power of the chimney. In boiler No. 58 the temperature is reduced from 645 degrees to 365 degrees, and the draught from $\frac{41}{100}$ of an inch to $\frac{32}{100}$ of an inch, or 22 per cent. This is with an 80-foot chimney. In the last case a reduction of temperature from 575 degrees to 373 degrees is accompanied by a reduction of draught from $\frac{97}{100}$ of an inch to $\frac{69}{100}$ of an inch, or 29 per cent. This is with a 140-foot chimney. Although the general effect of the flue heater in this respect is unfavorable, a larger amount of draught is required to operate the boiler in every instance where the average draught is given, when the heater is thrown out of use. This is not due to any peculiar action of the heater but evidently to the increased quantity of coal which must be burned in order to make up for its absence. It may be concluded that a plant of boilers working to the full capacity of the chimney without a heater will have no difficulty working with

TABLE No. 10. — *Influence of Flue Heater on the Draught.*

1. Number of boiler, .	57		58		59		60		–	
2. Height of chimney, ft.	80		80		80		110		140	
3. Conditions, . . .	Heater used.	Heater not used.	Heater used.	Heater not used.	Heater used.	Heater not used.	Heater used.	Heater not used.	Heater used.	Heater not used.
4. Coal per hour, . lbs.	760.3	843	683.1	894.1	852.7	875.6	491.7	547	2,952	3,282
5. Temperature gases entering chimney, deg.	279	452	365	645	254	342	231	399	373	575
6. Average draught suction inside damper, in.	.25	.27	.09	Not taken.	.17	.22	–	–	.64	.67
7. Draught suction with damper wide open, in.	.26	.30	.32	.41	.25	.27	.40	.51	.69	.97

a heater, in producing the same amount of steam, unless the temperature of the gases is excessive. If the temperature is excessive and the full capacity of the chimney is required, there is some doubt whether a heater could successfully be used.

The quantities given in Table No. 10 show the draught power of chimneys of different heights, supplied with gas of various temperatures. In this connection it may be added that the draught of another chimney having a height of 230 feet, supplied with gas at a temperature of 500 degrees, amounted to 1.6 inches. This and all the observations referred to were made in cold weather.

The information which the tests give upon the remaining subjects to which they refer is of a somewhat meagre character. Though in some cases it may be for this reason of little importance, it deserves a brief notice.

The effect of changing the proportions of air space in the grates is shown by the tests on boiler No. 21. With anthracite Lehigh coal, of which 8.7 pounds were consumed per square foot of grate per hour, the grates having 50 per cent. air space produced about 2 per cent. more evaporation per pound of combustible than those having 60 per cent. air space. With about one-half as much coal burned in a given time the gain was 8 per cent. in favor of the smaller air space. The results of repeated tests corroborated these figures. The reason for this action does not at first sight appear to be plain. Considering, however, that whatever air passes through the grate, beyond that needed for chemically perfect combustion, produces a loss of economy, and that an excess of air to a greater or less extent always attends combustion, the effect may be explained on the ground that the reduced amount of opening in the grates tends to cut off this source of waste. The effect appears to be greatest when the rate of combustion is low. In the case mentioned the rate was much below that required to work the boiler to its nominal capacity. The effect is small at the higher rate and the conclusion may be drawn that it is only under special conditions of work that the matter is of much importance.

The tests on boiler No. 19 furnish a case of economy produced by automatic regulation of the draught over hand regulation. The automatic regulation secured an increased evaporation amounting to 3.7 per cent. The hand regulation consisted in alternately opening the damper wide and changing it to a nearly closed position, so as to secure regular variations of pressure over a uniform range. These tests show the tendency to loss produced by an unsteady draught. They do not show, however, what may happen in the ordinary work of operating boilers. In the case given, the firing was good for both methods of regulation. In ordinary work variations occur not only in this important matter but in other respects, and the economy of automatic regulation may be greater or even less than that obtained in the special case cited. Owing to the important part which the personal element of the fireman plays there must be a large difference in the result produced in different cases, and the tests on some large plants, referred to in the memoranda relating to boiler No. 19, one of which gave a result favoring automatic regulation, and the other favoring hand regulation, show this to be true.

The use of an artificial draught, made by a fan supplying warm air to the ash-pit of boiler No. 17, produced a result which was not materially different from that obtained with a natural supply of unheated air. The fuel was a mixture of anthracite screenings and Cumberland coal. There was the slight gain of 2 per cent. figured on the weight of coal used, and less than 1 per cent. figured on combustible.

The addition of heating surface to boiler No. 4, by introducing pipes beneath the shell through which the feed-water passes before it enters the boiler, seemed to increase the evaporation per pound of coal 3.5 per cent. This gain does not count for much, because at the time when the pipes were introduced, other changes in the line of improvement were made, and this percentage simply represents the collective result. It is noted in these tests that the temperature of the escaping gases is low, being in the first test only 355 degrees. Little benefit can be expected from an increase of furnace surface in a

case like this, where there is an indication, in the small amount of waste heat, that the heating surface already provided absorbs about all the heat that can be given up to the boiler

The tests on boiler No. 8 furnish an instance where the wetting of Cumberland bituminous coal secured an appreciable advantage. By adding 5 per cent. of its weight of water, the evaporation, based on the dry weight, was increased 3 per cent.

According to the result of tests Nos. 130 and 131, the loss produced by banking a Cumberland coal fire was about 2 per cent.

The prevention of smoke was attained in an almost complete manner in the case of boiler No. 53, burning Cumberland bituminous coal, by the use of a sufficient quantity of air above the fuel and of superheated steam below the grate. The general economic result was, however, inferior to that obtained by boilers in which the smoke is not suppressed.

The indication of the calorimeter trials made in connection with the tests, so far as they have been conducted, is that the steam produced by boilers which do not superheat is in nearly a dry state. Horizontal tubular boilers Nos. 4, 6, 16, 18, 56, 62, 63 and 68 gave steam containing respectively 0.6, 0.5, 0.3, 0 3, 2.2, 0.7, 0.5 and 0.2 per cent. of moisture, the average being 0.7 per cent. Water-tube boilers Nos. 35, 57, 65, 71, 76 and 77 gave respectively 0.6, 1.3, 1.6, 0.4, 0.5 and 0.7 per cent., averaging 0.7 per cent. The Galloway boiler No. 70 gave 7 per cent., and the single boiler which was tested gave dry steam.

The remaining tests would be of greater value if the quality of the steam had been obtained. It is not unreasonable to apply the general results of a number of calorimeter tests on a given type of boiler to one of the same type where the quality of the steam is not known, but it is somewhat unsatisfactory when it is seen that boilers of one type, the horizontal type for example; give percentages of moisture varying from 0.2 to 2.2 per cent. The question naturally arises in a case where a high evaporation is produced, whether it is not due in a measure to the wet quality of the steam. This is quite a proper question

to raise, and one which cannot be definitely answered unless a calorimeter trial is made. In the absence of such a trial there are some external evidences which throw light upon the subject. If the steam is wet and it is used in an engine, the observant engine driver will be aware of the fact by the unusual presence of water in the cylinder. The steam which escapes from the indicator cock, when it is opened, will show an excessive amount of moisture. The water which is discharged by leaking flange joints, or by the leaking stuffing box of a valve in the steam-pipe, will clearly point to wet steam. The moisture will be seen at the vent of the safety valve if notice is taken of the escaping steam when the valve is opened. These indications can safely be credited when there is more than 3 per cent. of moisture. In regard to the application of this matter to the tests given in the paper, it may be said that there were none of these external evidences of wet steam in any case where the calorimeter trial was not made.

Little has been said here upon the subject of imperfect combustion. It has been incidentally mentioned in the treatment of boiler settings, where the effect of a supply of air above the fuel is considered. That imperfect combustion is a factor in the burning of bituminous coal, the results produced by the admission or exclusion of air clearly prove. That it is also a factor in the burning of other kinds of coal, no one will question. How far it has operated to affect the results of the various tests is a matter about which the reader must form his own opinion. The feeling of the writer is that imperfect combustion, which doubtless existed to a greater or less extent in all cases, is not sufficient to change the general conclusions thus far set forth. It is highly probable that a full knowledge of the character of the combustion in each case would have furnished a reason for a few individual results which, in the light of the data at hand, appear somewhat obscure. Doubtless a knowledge of the quality of the various fuels, as determined by chemical analysis, would also have been useful for the same end. The determination of these questions is the work of the chemist. It involves labor and expense which few care to un-

dertake, and on this account it is outside the province of tests of limited scope, like those treated of in the paper.

In conclusion, it should be stated that the various boilers and appliances to which the paper refers are not designated by their commercial names, and no mention is made of the locality where they are in use. The desire to give prominence to principles rather than to individual methods of carrying out the principles, and to remove from the discussion all matters bearing upon purposes of trade, has led to this course. Furthermore, it was on condition that the tests should be treated in this impersonal way that the interested parties, with a single exception, granted permission for the public use of the results. The exception is the case of the tests on boilers Nos. 32, 35, 38, 75 and 76, which are of the Babcock and Wilcox type. These are given with the permission of the manufacturers of the boilers, on behalf of whom the tests were made.

Boiler No. 1.

Kind of boiler,	Cast-iron sectional.
Number in use,	One.
Horse-power (basis 12 square feet),	Thirty-seven.
Kind of coal,	Anthracite broken.
Age,	Ten years.

Dimensions.

Number of sections 5×76,	380
Area of total heating surface,	443 sq. ft
Area of grate surface,	16.29 sq. ft.
Area through flue,	.97 sq. ft
Ratio total heating surface to grate surface,	27.2 to 1
Ratio grate to flue,	16.8 to 1
Chimney height,	100 ft.

	Test No. 1.	Test No. 2.
Area water-heating surface, square feet,	321	221
Area steam-heating surface, square feet,	122	222
Ratio water-heating surface to grate,	19.7 to 1	13.6 to 1

Results of Tests.

		Test No. 1.	Test No. 2.
Duration,	hrs.	11	11
Coal consumed,	lbs.	1,600	1,579
Percentage of ash,	%	9.1	10
Water evaporated,	lbs.	12,817	12,434
Coal per hour,	lbs.	145.5	143.5
Coal per hour per square foot grate,	lbs.	8.9	8.9
Water per hour,	lbs.	1,165.2	1,130.4
Water per hour per square foot water-heating surface,	lbs.	3.6	5.1
Horse-power developed,	H. P.	37.5	36.6
Boiler pressure,	lbs.	28.3	28.3
Temperature feed-water,	deg.	123	117
Temperature escaping flue gases,	deg.	575	540
Number degrees superheating,	deg.	25	153
Water per pound coal,	lbs.	8.01	7.87
Water per pound coal from and at 212 degrees,	lbs.	8.90	8.79
Water per pound combustible from and at 212 degrees,	lbs.	9.79	9.78

These tests commenced with a fire which had been banked thirteen hours before, and ended twenty-four hours afterwards with the fire in practically the same condition as at the start. The special object of the tests was to show the performance of the boiler when low water was carried, so as to increase the amount by which the steam was superheated. The increase in superheating, which was 128 degrees, seems to have had little effect upon the evaporative performance.

Boiler No. 2.

Kind of boilers,	One horizontal return tubular. One horizontal direct tubular.
Number used,	Two.
Horse-power (collective, basis 12 sq. ft.),	One hundred and seven.
Kind of coal,	Anthracite, Hazelton, Chestnut.
Age,	Fifteen years.

Dimensions.

	Return Tubular.	Direct Tubular.
Diameter each shell, in.	48	48
Length between heads and length of tubes, ft.	16	14
Number tubes 3 inches outside diameter,	48	45
Length combustion chamber, in.	–	38
Area of water-heating surface, sq. ft.	669	586
Area of steam-heating surface,*. sq. ft.	50	43
Area of grate surface, sq. ft.	19.9	21.2
Area through tubes, sq. ft.	1.98	1.86
Width of air spaces and metal bars in grates, in.	Air 3-8 Metal 5-8	Air 3-8 Metal 5-8
Distance grate to shell, in.	18	17
Distance bridge wall to shell, in.	7	–
Kind of brick setting,	Common.	Common.
Ratio water-heating surface to grate,	33.7 to 1	27.7 to 1
Ratio grate to tube area,	10 to 1	11.4 to 1

* This surface in the case of the return tubular boiler consisted of cast-iron pipes laid transversely under the boiler, behind the bridge wall, and through these pipes the steam from both boilers was conducted on test No. 3. These pipes were not in use on test No 4. In the case of the direct tubular boiler, the steam-heating surface consisted of the upper surface of the shell which was in part exposed to the heat of the escaping gases. This surface was probably inefficient, as it had not been cleaned for a long time.

Results of Tests.

		Test No. 3.	Test No. 4.
Manner of start and stop and kind of run,	.	Ordinary.	Ordinary.
Duration,	hrs.	10	9.67
Coal consumed (including wood for starting),	lbs.	3,163	3,374
Percentage of ash,	%	15.6	–
Water evaporated,	lbs.	26,187	29,562
Coal per hour,	lbs.	316.3	349
Coal per hour per square foot grate,	lbs.	7.7	8.5
Water per hour,	lbs.	2,618.7	3,057.1
Water per hour per square foot water-heating surface,	lbs.	2.09	2.44
Horse-power developed,	H. P.	79.4	92.7
Boiler pressure,	lbs.	73	71.6
Temperature feed-water,	deg.	200	200
Temperature escaping gases,	deg.	360	367
Degrees superheating,	deg.	66	None.
Water per pound coal,	lbs.	8.28	8.76
Water per pound coal from and at 212 degrees,	lbs.	8.66	9.16
Water per pound combustible from and at 212 degrees,	lbs.	10.25	10.85

A comparison of tests Nos. 3 and 4 shows the cost of superheating steam when the heat is derived from surface exposed to the products of combustion at the time when these are first discharged from the furnace. The loss in evaporative efficiency here was about 5.5 per cent., and number of degrees of superheating obtained 66.

In the same series of tests to which these belong, the effect of placing an auxiliary furnace beneath the superheating pipes, using coal at the rate of 4 pounds per square foot per hour on a grate having 7 square feet of surface, was to secure a superheating of 134 degrees, attended by a reduction of 9.2 per cent. in the evaporative efficiency. In another experiment on the same plant a superheating of 163 degrees was attended by a reduction of 10.2 per cent. in the evaporation per pound of total fuel used.

The same superheating pipes, placed over an independent

furnace and surmounted by a heater made of small pipes, presenting an aggregate of 60 square feet of surface, were attached to a single 80 horse-power boiler of the horizontal tubular type, some 75 feet distant. A test on these, during which all the steam generated by the boiler passed through the superheater, showed that 473 pounds of anthracite coal were required to superheat 23,609 pounds of steam made by the consumption of 2,657 pounds of coal, the number of degrees of superheating being 228. The rate of combustion in the boiler furnace was 6.3 pounds per square foot of grate per hour, and in the superheater 4.8 pounds. The evaporation of the boiler per pound of combustible from and at 212 degrees was 10.95 pounds; temperature of feed-water, 215 degrees; temperature of gases, 290 degrees; temperature of gases leaving superheater, 394 degrees. In this case a superheating of 228 degrees required the consumption of an additional 17.8 per cent. of coal in the independent furnace.

The quantity of coal required for superheating, in all these cases, is greater than that which would be expected if account be taken simply of the additional heat of the steam. The difference, however, is not more than can fairly be attributed to a slightly moist condition of the steam generated by the boiler and to loss of heat produced by radiation from the pipe leading from the boiler to the superheater, and by radiation from the superheater itself.

The general results of these tests, considering the kind of coal burned, are favorable.

BOILER NO. 3.

Kind of boiler,	"Double-deck," hor. ret. tub.
Number used,	One.
Horse-power (basis 15 square feet),	Eighty-five.
Kind of coal,	Bituminous, Cumberland.
Age,	One month.

Dimensions.

Diameter of lower shell,	54	in.
Diameter of upper shell,	32	in.
Length of shells and tubes,	12	ft.

Number of tubes (3 inches diameter),	118	
Area of water-heating surface,	1,221	sq. ft.
Area of steam-heating surface,	60	sq. ft.
Area of grate surface,	20	sq. ft.
Area through tubes,	4.9	sq. ft.
Ratio water-heating surface to grate,	61	to 1
Ratio steam-heating surface to grate,	3	to 1
Ratio grate to tube area,	4.1	to 1
Kind of brick setting,	Common.	

Results of Tests.

	Test No. 5.	
Manner of start and stop,	Running.	
Kind of run,	Continuous.	
Duration,	12	hrs.
Coal consumed,	1,912	lbs.
Percentage of ash,	7	%
Water evaporated,	19,991	lbs.
Coal per hour,	159.3	lbs.
Coal per hour per square foot of grate,	7.96	lbs.
Water per hour,	1,665.9	lbs.
Water per hour per square foot of water-heating surface,	1.36	lbs.
Horse-power developed,	50.4	H. P.
Boiler pressure,	81	lbs.
Temperature of feed-water,	197	deg.
Temperature of escaping gases,	322	deg.
Percentage of moisture in steam,	0.5	%
Water per pound of coal,	10.45	lbs.
Water per pound of coal from and at 212 degrees,	10.98	lbs.
Water per pound of combustible from and at 212 degrees,	11.81	lbs.

The principal feature of boiler No. 3 is the large extent of heating surface in proportion to grate surface. It is secured by filling the lower shell completely full of tubes and providing a shell above it to which it is attached by necks. The water in the upper shell is carried at about the middle point. The course of the products of combustion is similar to that followed in the ordinary form of horizontal tubular boiler. The brick setting is arched over the top, leaving the whole of the upper shell exposed to the heat of the escaping gases, thus providing a small amount of steam-heating surface. The tube opening, compared with area of grate, is much larger than that given by

the horizontal tubular boiler, and it may be questioned whether some of the tubes are not on this account ineffective and therefore unnecessary.

The large measure of heating surface served to absorb all the heat possible from the products of combustion, since the temperature of the gases leaving the boiler was reduced to 322 degrees, which is a trifle less than the temperature of the steam and water within the boiler.

Boiler No. 4.

Kind of boilers,	Horizontal return tubular.
Number used,	Two.
Horse-power (collective, basis 12 sq. ft.),	One hundred and three.
Kind of coal,	Bituminous, Cumberland.
Age,	Several years.

Dimensions.

Diameter of each shell,	48	in.
Length between heads and length of tubes,	15	ft.
Number of tubes (collective) 3 inches outside diameter,	99	
Area of heating surface,	*1,235	sq. ft.
Area of grate surface (common to two boilers),	40.5	sq. ft
Area through tubes,	4.1	sq. ft.
Area through flue,	2.7	sq. ft
Chimney height,	130	ft.
Distance of grate to shell,	20	in.
Ratio of heating surface to grate,	30.5	to 1
Ratio of grate to tube area,	9.9	to 1
Ratio of grate to flue area,	15	to 1

* This is the heating surface relating to test No. 6. Test No. 7 was made after the heating surface had been increased sixty square feet by the introduction of pipes and surface behind the bridge wall Draught aided by a fan in both cases.

Results of Tests.

	Test No. 6.	Test No. 7.
Manner of start and stop, ...	Running.	Running.
Kind of run, ...	Continuous.	Continuous
Duration, ... hrs.	5.25	6
Coal consumed, ... lbs.	2,302	2,441
Percentage of ash, ... %	9.6	10.5
Water evaporated, ... lbs.	19,550	21,955
Coal per hour, ... lbs.	438.5	406.8
Coal per hour per square foot of grate, . lbs.	10.8	10.0
Water per hour, ... lbs.	3,723.8	3,659.2
Water per hour per square foot of heating surface, ... lbs.	3.01	2.96
Horse-power developed, ... H. P.	117.3	115.1
Boiler pressure, ... lbs.	68	63
Temperature of feed-water, ... deg.	160	160
Temperature of escaping gases, . . . deg.	355	346
Percentage of moisture in steam, . . %	0.6	3.0
Water per pound of coal, ... lbs.	8.49	8.99
Water per pound of coal from and at 212 degrees, ... lbs.	9.22	9.77
Water per pound of combustible from and at 212 degrees, ... lbs.	10.19	10.91

The tests on boiler No. 4 were designed to show the effect upon the economy produced by increasing the heating surface of the boiler, placing the added surface beneath the shell.

The change in the setting of the boilers, involved in the introduction of the new heating surface, necessitated the removal of a bridge wall, which was located at the rear end, and the enlargement of the space behind and above the front bridge wall. The original opening above the walls was too small. A change was also made in the speed of the blower, which was at times too low to maintain the desired supply of steam. For these reasons the comparison does not show simply the effect produced by the enlargement of heating surface.

The water from the feed pump first passed through the pipes that were introduced beneath the shells, and after circulating through them was discharged into the steam space of the

boiler. There is a marked difference in the results of the two tests in the quality of the steam, and this may be attributed to the discharge of the feed-water into the steam space.

Taking the results as they stand, the gain produced by the various changes, corrected for difference in quality of steam and based on coal, is 3.5 per cent.

The general results of the tests are inferior to many given in the paper. The percentage of ash is high for this class of coal — an indication of inferior quality.

(See memoranda regarding boiler No. 60.)

Boiler No. 5.

Kind of boilers,	Horizontal return tubular.
Number used,	Six.
Horse-power (collective, basis 12 sq. ft.),	Three hundred and thirty-eight.
Kind of coal,	Anthracite Lackawanna, Broken.
Age,	Six years.

Dimensions.

Diameter of each shell,	48	in.
Length between heads and length of tubes,	15	ft.
Number of tubes (collective) 3 inches outside diameter,	288	
Area of water-heating surface,	4,056	sq. ft.
Area of steam-heating surface,	540	sq. ft.
Area of grate surface,	120	sq. ft.
Area through tubes,	11.9	sq. ft.
Area through chimney,	11.1	sq. ft.
Height of chimney,	100	ft.
Ratio of water-heating surface to grate,	33.8	to 1
Ratio of steam-heating surface to grate,	4.5	to 1
Ratio of grate to tube area,	10.1	to 1
Kind of brick setting,	Common.	

Results of Test. (Average of three.)

	Test No. 8.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	12	hrs.
Coal fired (including wood equivalent),	16,003	lbs
Percentage of ash (including some unburned coal),	16.7	%

	Test No. 8.	
Water evaporated,	136,034	lbs.
Coal per hour,	1,333.6	lbs.
Coal per hour per square foot of grate,	11.11	lbs.
Water per hour,	11,336.1	lbs.
Water per hour per square foot of water-heating surface,	2.79	lbs.
Horse-power developed,	345	H. P.
Boiler pressure,	84.6	lbs.
Temperature of feed-water,	198.6	deg.
Temperature of escaping gases,	482	deg.
Water per pound of coal,	8.50	lbs.
Water per pound of coal from and at 212 degrees,	8.96	lbs.
Water per pound of combustible from and at 212 degrees,	10.73	lbs.

Boiler No. 5 is set in such a manner that the upper surface of the shell is exposed to the heat of the escaping gases, thus providing steam-heating surface. The location of this surface being such as to receive a deposit of soot, it is doubtless inefficient for its purpose.

The temperature of the escaping gases in this test is high for anthracite coal. Considering the rate of combustion, which is medium, and the ratio of heating surface to grate surface, which is sufficient, there is an indication here of inefficiency of the heating surface, such as would be produced by a deposit of scale on the interior of the boiler. The economic result is somewhat lower than the best figures given in the paper — as would be expected from the waste heat of the flue.

Boiler No. 6.

Kind of boilers,	"Double-deck," hor. ret. tub.
Number used,	Three.
Horse-power (collective, basis 15 sq. ft.),	Three hundred and ninety.
Age,	New.

Dimensions.

Diameter of lower shell,	60	in.
Diameter of upper shell,	34	in.
Length of shell and tubes,	15	ft.
Number of tubes (collective) 3 inches outside diameter,	420	

Area of water-heating surface,	5,850 sq. ft.
Area of steam-heating surface,	300 sq. ft.
Area of grate surface,	90 sq. ft.
Area through tubes,	17.3 sq. ft.
Area through chimney,	11.1 sq. ft.
Height of chimney,	100 ft.
Ratio of water-heating surface to grate surface,	65 to 1
Ratio of steam-heating surface to grate surface,	3.3 to 1
Ratio of grate to tube area,	5.2 to 1
Ratio of grate to chimney area,	8.1 to 1
Kind of brick setting,	Common.

Results of Tests. (Average of three.)

	Test No. 9.	Test No. 10.
Kind of coal,	Anthracite, Lackawanna, Broken.	Bituminous, Geo.'s Creek Cumberland.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.
Duration, . . . hrs.	12	11.8
Coal consumed dry (including wood equivalent), . . . lbs.	15,385	11,646
Percentage of ash, . . . %	12.3	6.7
Water evaporated, . . . lbs.	141,574	129,348
Coal per hour, . . . lbs.	1,282.1	987
Coal per hour per square foot grate, . lbs.	14.25	10.97
Water per hour, . . . lbs.	11,797.8	10,961.7
Water per hour per square foot water-heating surface, . . . lbs.	2.02	1.87
Horse-power developed, . . . H.P.	359	331.8
Boiler pressure, . . . lbs.	82.5	81.7
Temperature of feed-water, . . deg.	199.3	205
Temperature of escaping gases, . . deg.	392	389
Percentage of moisture in steam, . %	–	0.5
Water per pound of coal, . . . lbs.	9.20	11.08
Water per pound of coal from and at 212 degrees, . . . lbs.	9.65	11.55
Water per pound of combustible from and at 212 degrees, . . . lbs.	11.11	12.42

Boiler No. 6 is of the same type as boiler No. 3, its principal feature being the large extent of heating surface and tube area. The tests on boiler No. 6 were made in the same series as those of boiler No. 5, one set of boilers being used when

the other set was idle, and both being employed for the same work.

A comparison of tests Nos. 8 and 9 may be made to show the efficiency of the two types of boilers. Both tests were made with coal from the same cargo. The double-deck boiler secured a somewhat better result than the common boiler, the figures per pound of combustible being 11.11 and 10.73. The difference is 3.5 per cent. The reason for this result is seen in the reduced quantity of waste heat. The temperature of the escaping gases in the two cases is 482 degrees and 392 degrees, respectively. The reduction is evidently due in a measure to the increased amount of heating surface which the double-deck boiler provides. There is 5,850 square feet of surface in this boiler, against only 4,056 square feet in the common boilers. While an improvement might be expected from this cause, the whole of the improvement cannot be attributed to the difference in the type of boiler, because the double-deck boilers were new and clean, while the common boilers were old and presumably somewhat inefficient from long usage. It would not be unreasonable to attribute the whole of this small improvement (which, as noted, is only 3.5 per cent.) to the difference in age and condition of the heating surfaces, rather than to the change in the type of boiler. These results do not necessarily show that the use of a large amount of heating surface is inadvisable, for it cannot be denied that if the heating surface in the common boilers was increased to 5,850 square feet, and so arranged as to absorb the waste heat, these boilers would be fully as economical and possibly more economical than the double-deck boiler. The extra surface in the double-deck boiler seems to be largely inefficient, as might be expected from the large extent of tube area which this system requires.

The results of tests Nos. 9 and 10 may be compared to show the relative economy of Lackawanna coal, broken size, and George's Creek Cumberland coal. The bituminous coal, considered by itself, gave exceptionally good results. It is not improbable that the large draught area through the tubes is a

favorable condition in cases like this, where the gaseous element of combustion forms so prominent a feature. If this be so, the comparison between the economy of the two fuels shows a larger difference in favor of the bituminous coal than would be shown on some different type of boiler. Taking the figures as they stand, however, there is a difference of 11.55 — 9.65 equals 1.90 pounds of water in favor of the performance of the bituminous coal, which is a gain of nearly 20 per cent. over that of the anthracite coal, and this gain represents a saving in the quantity of bituminous coal required to do a given amount of work of 16.4 per cent.

A marked feature in the comparison of the two kinds of fuel is the difference in the quantity of ash. It is 12.3 per cent. for the anthracite coal, and 6.7 per cent. for the bituminous coal.

Boiler No. 7.

Kind of boilers,	Horizontal return tubular.
Number used,	Six.
Horse-power (collective, basis 12 sq. ft.),	Four hundred and thirty.
Kind of coal,	Mixture of Anthracite Screenings and Nova Scotia Culm.
Age,	Two years.

Dimensions.

Diameter of each shell,	60	in.
Length between heads and length of tubes,	15	ft.
Number of tubes (collective) 3 inches outside diameter,	385	
Area of heating surface,	6,204	sq. ft.
Area of grate surface,	150	sq. ft.
Area through tubes (at smallest section),	6.42	sq. ft.
Area through chimney,	16	sq. ft.
Height of chimney,	120	ft.
Ratio of heating surface to grate surface,	41.4	to 1
Ratio of grate surface to smallest tube area,	23.4	to 1
Ratio of grate surface to chimney area,	9.2	to 1
Kind of brick setting,	Common with fan draught.	

Results of Test.

	Test No. 11.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	10.5	hrs.
Coal consumed moist (including wood equivalent),	11,265	lbs.
Proportion of bituminous coal to whole,	.178	
Percentage of ash and waste coal,	15.4	%
Water evaporated,	78,849	lbs.
Coal per hour,	1,072.8	lbs.
Coal per hour per square foot of grate,	7.15	lbs.
Water per hour,	7,509.4	lbs.
Water per hour per square foot of heating surface,	1.21	lbs.
Horse-power developed,	250.3	H. P.
Boiler pressure,	45	lbs.
Temperature of feed-water,	89	deg.
Temperature of escaping gases,	305	deg.
Draught suction of chimney,	3-8	in.
Draught pressure of fan,	0 in. to ½	in.
Water per pound of coal,	7.00	lbs.
Water per pound of coal from and at 212 degrees,	8.17	lbs.
Water per pound of combustible from and at 212 degrees,	9.66	lbs.

The setting in boiler No. 7 was arranged in the usual manner of horizontal return tubular boilers, with the exception that provision was made for using a fan discharging into the ash-pits to augment the draught, and this provision was availed of to a greater or less extent in the ordinary work of the boilers. The tubes in the boilers were divided, and part of them were used for carrying the products of combustion in one direction while the remainder returned them in the other direction. This arrangement introduced a necessity for the use of the fan when it might otherwise have been avoided.

The interest in this test centres in the kind of fuel burned, and the arrangement of tubes noted. Subsequent tests, made at intervals of about a year and using different kinds of the cheap grades of anthracite coal, gave the following results:—

Kind of anthracite coal, . .	Screenings.	Buckwheat.	Pea and Dust.
Proportion of Nova Scotia coal, ...	.14	.055	.105
Percentage of ash, . . %	20	18	19.8
Horse-power developed, . H.P.	380	368	561
Temperature of escaping gases, ... deg.	348	337	407
Water per pound of coal from and at 212 degrees, lbs.	7.95	8.92	8.26
Water per pound of combustible from and at 212 degrees, . . . lbs.	9.93	10.87	10.32
Draught pressure at blower, in.	–	–	0 to 1½

The results of all the tests on boiler No. 7 give an average of 8.32 pounds of water from and at 212 degrees per pound of coal. The coal was slightly moist, say 4 per cent.

It is to be noted that the rate of power developed was low. The last test gave about the maximum which, under the circumstances, could practically be obtained.

There was a coil of pipe in the flue containing one-twentieth of the total heating surface given above. On test No. 11 the feed-water, which passed through this coil, after leaving the injector, was heated 13 degrees, the initial temperature being 155 degrees.

Boiler No. 8.

Kind of boiler, ...	"Double-deck," hor. ret. tub.
Number used, ...	One.
Horse-power (basis 15 square feet), .	One hundred.
Age, ...	New.

Dimensions.

Diameter of lower shell, ...	54	in.
Diameter of upper shell, ...	36	in.
Length of shell and tubes, ...	15	ft.
Number of tubes 3 inches outside diameter, . . .	114	
Area of water-heating surface, ...	1,521	sq.
Area of steam-heating surface, ...	88	sq.
Area of grate surface, ...	22.5	sq.

Area through tubes,	9.4 sq. ft.
Area through chimney,	7.1 sq. ft
Height of chimney,	70 ft.
Width of air spaces and metal bars in grates,	3-8 in.
Ratio of water-heating surface to grate surface,	67.6 to 1
Ratio of steam-heating surface to grate surface,	3.9 to 1
Ratio of grate surface to tube area,	4.8 to 1
Kind of brick setting,	Passages in walls supplying air to sides of furnaces and to bridge walls.

Results of Tests.

		Test No. 12.	Test No. 13.	Test No. 14.	Test No. 15.
Kind of fuel,		Mixture 1 part Nova Scotia Culm, 3 parts Pea and Dust.	Delaware and Lackawanna, Broken, Anthracite.	George's Creek Cumberland, Bituminous.	Nova Scotia Culm.
Manner of start and stop and kind of run,		Av. 3 days. Ordinary.	Av. 2 days. Ordinary.	Av. 2 days. Ordinary.	One day. Ordinary.
Duration,	hrs.	11.5	11.5	11.5	9.5
Coal consumed dry (including wood equivalent),	lbs.	2,983	2,485	2,131	2,390
Percentage of ash,	%	14.7	15.5	6.7	10.4
Water evaporated,	lbs.	24,671	21,091	21,137	18,938
Coal per hour,	lbs.	259.3	216.1	185.4	247.7
Coal per hour per square foot grate,	lbs.	11.5	9.4	8.2	11.2
Water per hour,	lbs.	2,145	1,834	1,838	1,994
Water per hour per square foot water-heating surface,	lbs.	1.4	1.2	1.2	1.3
Horse-power developed,	H. P.	64.3	55	55	59.8
Boiler pressure,	lbs.	75.3	74	74.2	71.7
Temperature of feed-water,	deg.	206	211	211	210
Temperature of escaping gases,	deg.	339	335	348	348
Moisture in steam, by calorimeter,	%	1.2	–	–	–
Water per pound coal,	lbs.	8.27	8.48	9.92	7.93
Water per pound coal from and at 212 degrees,	lbs.	8.59	8.78	10.26	8.21
Water per pound combustible from and at 212 degrees,	lbs.	10.07	10.39	10.99	9.19

NOTE. — The coals when fired contained the following percentages of moisture: Mixed fuel, 6 per cent.; Cumberland, 2-5 per cent.; Nova Scotia culm, 7 per cent.

Boiler No. 8, like No. 6, has a lower shell completely filled with tubes, and an upper shell attached by necks in the manner of a steam drum. During test No. 13 the entrances to the passages in the walls, through which air ordinarily enters the setting, were closed by means of cement. During one day's run of test No. 14 the coal was dry, and during the other day's run the coal was wet, after being weighed, with 5 per cent. of its weight of water. The evaporative performance on the second day's run, that is, using the wet coal, was 3 per cent. higher than on the first day's run.

These tests give an indication of the relative economy of the various fuels which were tried. The cost of these coals per ton of 2,240 pounds, and the cost of fuel required to evaporate a given quantity of water, say 30,000 pounds from and at 212 degrees on the basis of these quotations and of the results of the tests, are as follows: —

	Mixture Pea and Dust 3 parts, Nova Scotia Culm 1 part.	Delaware and Lackawanna, Anthracite, Broken.	George's Creek Cumberland, Bituminous.	Nova Scotia Culm.
Cost of 2,240 pounds coal, .	$4.02	$5.90	$6.75	$3.80
Cost of coal for 30,000 pounds steam, ...	6.31	9.18	8.91	7.14

This comparison is of little value at the present time (September, 1888), when the prices of the same grades of coal are entirely different, but it suggests many possibilities. Making a comparison on the basis of the quantity of water evaporated per pound of coal, it appears that the best result was produced by the Cumberland coal and the poorest result by the Nova Scotia culm. The Cumberland did 17 per cent. better than the anthracite, 19 per cent. better than the mixed fuel, and 25 per cent. better than the Nova Scotia culm.

Looking at the results as a whole, there is evidence that they are inferior. Boiler No. 6, which is of similar type, gave a higher evaporation, both with anthracite and with Cumber-

land coal, but it worked under different conditions. The quantity of power developed here is notably low — little more than half of the nominal power. There was probably too much surface. As elsewhere remarked, the arrangement of the tubes is such that a part of the surface is inefficient and sometimes almost useless. The lower power developed made this defect more prominent than it would otherwise have been.

A low temperature of the escaping gases is an indication of economical performance, but it is not a sure guide in the matter, as these experiments prove.

Subsequent tests were made, using a mixture of pea and dust coal and Nova Scotia culm, having the same proportions as those used in test No. 12, to determine the effect of working the boilers to greater capacity. The rate of combustion was increased to 15.5 pounds of coal per square foot of grate per hour, and the amount of horse-power to 92.7. The evaporation from and at 212 degrees per pound of coal was 9.18 pounds, and per pound of combustible 10.77 pounds. These quantities are about 7 per cent. higher than those which obtained with the earlier tests. The temperature of the waste gases on the last tests was 375 degrees.

BOILER No. 9.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Fifty-four.
Age,	Several years.

Dimensions.

Diameter of each shell,	48	in.
Length between heads and length of tubes,	15	ft.
Number of tubes 3 inches outside diameter,	49	
Area of heating surface,	644	sq. ft.
Area of grate surface,	20	sq. ft.
Area through tubes,	2	sq. ft.
Width of air spaces and metal bars in grates,	3-8	in.
Distance of grate to shell,	27	in.
Distance of bridge wall to shell,	8	in.
Ratio of heating surface to grate surface,	32.2	to 1
Ratio of grate surface to tube area,	9.9	to 1
Kind of brick setting,	Common.	

Results of Tests.

		Test No. 16.	Test No. 17.	Test No. 18.	Test No. 19.
Kind of coal,		George's Creek Cumberland, Bituminous.	Delaware and Hudson, Lackawanna, Anthracite, Broken.	Mixture 1 part Cumberland, 2 parts Pea and Dust.	Mixture 1 part Nova Scotia Culm, 2 parts Pea and Dust.
Manner of start and stop and kind of run,		Ordinary.	Ordinary.	Ordinary.	Ordinary.
Duration,	hrs.	11.2	11.2	11.2	11.2
Coal consumed dry (including wood equivalent),	lbs.	2,277	2,266	1,878	2,080
Percentage of ash,	%	11.1	14.2	21.3	26.2
Water evaporated,	lbs.	20,464	18,385	13,144	13,230
Coal per hour,	lbs.	202.4	201.4	167	184.9
Coal per hour per square foot of grate,	lbs.	10.1	10.1	8.3	9.2
Water per hour,	lbs.	1,819	1,634.3	1,168.4	1,176.1
Water per hour per square foot heating surface,	lbs.	2.8	2.5	1.8	1.8
Horse-power developed,	H. P.	60	53.9	38.5	38.8
Boiler pressure,	lbs.	69.4	69.4	71.7	71.6
Temperature of feed-water,	deg.	119.4	120.5	119.7	120.4
Temperature of escaping gases,	deg.	435	443	430	406
Number of firings,		17	12	14	15
Number of times slicing-bar was used,		15	4	8	18
Water per pound of coal,	lbs.	9.08	8.20	7.10	6.46
Water per pound of coal from and at 212 degrees,	lbs.	10.25	9.24	7.99	7.27
Water per pound of combustible from and at 212 degrees,	lbs.	11.52	10.76	10.18	9.87

NOTE. — The mixed fuels were wet before firing with 5 per cent. of their weight of water.

The tests on boiler No. 9 were made to show the relation which exists in the matter of economy between various kinds of coal. The tests were made upon old boilers in a locality favorable to the production of scale, and it is presumed from the high temperature of the escaping gases that the heating surfaces had become somewhat inefficient from this cause.

The Cumberland coal gave the highest economic result, expressed in pounds of water evaporated, and the mixture of Nova Scotia culm and pea and dust gave the lowest result.

The Cumberland coal result was superior to the anthracite result some 10 per cent. and to the remaining fuels 28 per cent. and 41 per cent. respectively. There is evidence of inferior quality in all these fuels, excepting the anthracite coal, in the fact of the comparatively large percentage of ash. Eleven per cent. of ash is high for Cumberland coal of good quality. The quantities of ash given for the mixed fuels, viz., 21 per cent. and 26 per cent., are exceedingly large.

A feature of the results is the relative amount of power developed by the various fuels. The dampers were kept wide open during each test and the boilers produced a maximum quantity of steam under each condition. The Cumberland coal produced the largest amount, viz., 120 horse-power, and this is 22 per cent. above the nominal capacity. Then comes the anthracite coal and finally the mixed fuels. The mixed fuels produced 22 per cent. below the rated power of the boilers. Another feature is the labor involved in using the various fuels, as indicated by the number of times the slicing-bar was employed in breaking up the bed of coal. The anthracite coal gives the most favorable showing, while the mixture of culm and pea and dust gives the least favorable showing. The difference in the labor involved in slicing a fire four times per day and eighteen times per day is considerable.

The real economy of these various fuels depends upon their cost. In the table below, the cost of each fuel per ton of 2,240 pounds and the cost of coal required for generating 30,000 pounds of steam on the basis of the results obtained, according to quotations of prices at the time the tests were made, are given :—

	Cumberland.	Anthracite.	Mixture Cumberland and Pea and Dust.	Mixture Culm and Pea and Dust.
Cost of coal per ton of 2,240 pounds, ...	$5.90	$5.60	$4.47	$3.75
Cost of coal required to evaporate 30,000 pounds of water from and at 212 degrees, . .	7.70	8.11	7.50	6.88

The extreme difference in these figures is $1.23, which corresponds to 15 per cent., and this occurs between the anthracite coal, which is the most easily worked, and the mixed fuel containing culm, which requires the most labor in firing. If one fireman be assumed capable of handling ten tons of anthracite coal, broken size, per day, and his wages are $2.00 per day, the cost of fireman's labor represents 3.6 per cent. of the cost of fuel. A saving of 15 per cent. in the cost of fuel, due to using the mixture named, is sufficient to cover an increased cost of labor corresponding to the employment of another fireman at the wages named, and still have 11.4 per cent. remaining for a net saving. These figures and comparisons apply only to the conditions of cost and performance which obtained in this particular case. They suggest, however, an important line of investigation for those who wish to burn the most economical fuel.

On a subsequent occasion tests were made upon the same boilers, first with Franklin coal and then with Kalmia coal, each of which was quoted at $6.75 per ton. The results in pounds of water from and at 212 degrees per pound of coal was 9.78 pounds and 9.68 pounds respectively. The improvement over the Anthracite Lackawanna is largely due to the reduced quantity of ash. The percentage of ash was in the case of each of the two first-named fuels 10.8 per cent., while in the last it was 14.2 per cent.

BOILER NO. 10.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Sixty-three.
Kind of coal,	Mixture two parts Screenings, one part Nova Scotia Culm.
Age,	Several years.

Dimensions.

Diameter of each shell,	54	in.
Length between heads and length of tubes,	15	ft.
Number of tubes 3 inches outside diameter,	60	

Area of heating surface,	757 sq. ft.
Area of grate surface,	22.5 sq. ft.
Area through tubes,	2.5 sq. ft.
Width of air spaces and metal bars in grates,	3-8 in.
Distance of grate to shell,	27 in.
Distance of bridge wall to shell,	8 in.
Space behind bridge wall,	Filled, inclined covering.
Ratio of heating surface to grate surface,	33.7 to 1
Ratio of grate surface to tube area,	9 to 1
Kind of brick setting,	Passages in walls supplying air to sides of furnace and top of bridge wall.

Results of Tests. (Average of two days.)

		Test No. 20.	Test No. 21.
Conditions regarding air passages,		Air passages open.	Air passages closed.
Manner of start and stop and kind of run,		Ordinary.	Ordinary.
Duration,	hrs.	11.4	10.8
Coal consumed dry (including wood equivalent),	lbs.	2,820	2,673
Percentage of ash,	%	14.3	16.1
Water evaporated,	lbs.	17,828	16,557
Coal per hour,	lbs.	297.9	248.7
Coal per hour per square foot of grate,	lbs.	11.02	11.05
Water per hour,	lbs.	1,567.7	1,541.3
Water per hour per square foot heating surface,	lbs.	2.06	2.03
Horse-power developed,	H. P.	53.7	52.8
Boiler pressure,	lbs.	68.9	68.7
Temperature of feed-water,	deg.	72.2	71.6
Temperature of escaping gases,	deg.	453	461
Draught suction,	in.	0.36	0.36
Water per pound of coal,	lbs.	6.32	6.19
Water per pound of coal from and at 212 degrees,	lbs.	7.44	7.30
Water per pound of combustible from and at 212 degrees,	lbs.	8.69	8.69

NOTE. — The coal when fired contained 5 per cent. of its weight of water.

The object of the tests on boiler No. 10 was the determination of the effect produced by excluding the air from the passages in the walls, and thereby from entrance over the burning

fuel, this being done in a case where the fuel was a cheap mixture of screenings and bituminous coal. During the test with the passages open, the air registers in the fire doors were closed, while during the test with the passages shut, these registers were open a part of the time.

The results of the tests do not differ much from each other. On the basis of coal used there appears to be a loss of about 2 per cent., due to closing the air passages, but on the basis of combustible, there is an exact agreement in the results. The difference is so small that it is hardly worth while to consider it. This comparison is not made between admitting air above the fuel and not admitting it at all, but upon two methods of admitting air; one the common method of introducing it through the fire door, and the other, a special method of carrying it first through the side walls where it becomes somewhat heated, and finally discharging it through distributed openings on the sides of the furnace and on the top of the bridge wall.

The results of this comparison show that the manner in which the gaseous products of the furnace appear to be consumed, as viewed by the eye of an observer, does not necessarily indicate much as to the true economy with which the combustion takes place. As thus viewed there was a marked improvement in the character of the combustion when the air passages were open, over the appearance when they were closed.

The boilers developed less than their rated capacity, even with a constant draught of ⅜-inch water pressure, which is the full draught of a 100-foot chimney. The economic results appear to be low, but in partial explanation of this the high temperature of the escaping gases may be noticed.

BOILER No. 11.

Kind of boilers, ...	"Double-deck," hor. ret. tub.
Number used, ...	Four.
Horse-power (collective, basis 15 sq. ft.),	Three hundred and twenty.
Kind of coal, ...	Eureka Cumberland, Bituminous.
Age, ...	New.

Dimensions.

Diameter of lower shell,	54	in.
Diameter of upper shell,	32	in.
Length of shells and tubes,	12	ft.
Number of tubes (collective) 3 inches outside diameter,	472	
Area of water-heating surface,	4,972	sq. ft.
Area of steam-heating surface,	320	sq. ft.
Area through tubes,	19.5	sq. ft.
Area of grate surface,	80	sq. ft.
Width of air spaces and metal bars in grates,	3-8	in.
Ratio of water-heating surface to grate surface,	62.1	to 1
Ratio of steam-heating surface to grate surface,	4	to 1
Ratio of grate to tube area,	4.1	to 1
Kind of brick setting,	Common.	

Results of Tests. (Average of two.)

	Test No. 22.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	12.25	hrs.
Coal consumed dry (including wood equivalent),	9,000	lbs.
Percentage of ash,	9.7	%
Water evaporated,	92,355	lbs.
Coal per hour,	741.8	lbs.
Coal per hour per square foot of grate,	9.3	lbs.
Water per hour,	7,539.2	lbs.
Water per hour per square foot of water-heating surface,	1.5	lbs.
Horse-power developed,	231.4	H. P.
Boiler pressure,	82	lbs.
Temperature of feed-water,	190	deg.
Temperature of escaping gases,	375	deg.
Water per pound of coal,	10.26	lbs.
Water per pound of coal from and at 212 degrees,	10.86	lbs.
Water per pound of combustible from and at 212 degrees,	12.03	lbs.

These boilers, like those designated Nos. 3, 6 and 8, are novel in having a large extent of heating surface and large area through the tubes in proportion to their grate surface.

The results here obtained add weight to the view expressed elsewhere that much of the excessive area of heating surface in this type of boiler is useless.

The evaporation per pound of combustible from and at 212 degrees exceeds 12 pounds a trifle — which is a good result — but not much above many given in the paper for boilers of the ordinary type.

BOILER No. 12.

Kind of boiler,	Vertical tubular (rolling-pin).
Number used,	One.
Horse-power (basis 10 square feet),	One hundred and forty.
Kind of coal,	Delaware and Lackawanna, Anthracite, Broken.
Age,	Ten years.

Dimensions.

Diameter of main shell,	90 in.
Diameter of drum and water leg,	29 in.
Length of main shell and tubes,	9 ft. 9 in.
Number of tubes 2 inches outside diameter,	248
Area of water-heating surface,	941 sq. ft.
Area of steam-heating surface,	426 sq. ft.
Area of total heating surface,	1,367 sq. ft.
Area of grate surface,	45.6 sq. ft.
Area through tubes,	4.1 sq. ft.
Width of air spaces and metal bars in grates,	1-2 in.
Area through stack,	8.7 sq. ft.
Height of stack,	60 ft.
Ratio of water-heating surface to grate surface,	20.6 to 1
Ratio of steam-heating surface to grate surface,	9.3 to 1
Ratio of total heating surface to grate surface,	30 to 1
Ratio of grate to tube area,	11 to 1
Kind of brick setting,	Common.

Results of Tests.

	Test No. 23.	Test No. 24.
Conditions,	Damper wide open, maximum capacity.	Damper partially closed.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.
Duration, ... hrs.	11.7	11.2
Coal consumed (including wood equivalent), lbs.	9,161	5,705
Percentage of ash, ... %	8.5	8.6
Water evaporated, ... lbs.	61,355	44,597
Coal per hour, ... lbs.	783	507.1
Coal per hour per square foot of grate, . lbs.	17.1	11.1
Water per hour, ... lbs.	5,244	3,964.2
Water per hour per square foot of water-heating surface, ... lbs.	5.6	4.3
Horse-power developed, ... H. P.	169.8	128.2
Boiler pressure, ... lbs.	78	79
Temperature of feed-water, ... deg.	132	132
Temperature of escaping gases, . . deg.	600	480
Number of degrees of superheating, . deg.	–	90
Water per pound of coal, ... lbs.	6.70	7.82
Water per pound of coal from and at 212 degrees, ... lbs.	7.23	8.75
Water per pound of combustible from and at 212 degrees, ... lbs.	8.18	9.56

Boiler No. 12 is a typical vertical tubular boiler of the rolling-pin form. The setting consists of a plain brick wall of circular shape surrounding the shell, and extending to a height of 10 or 12 feet above the upper tube sheet.

One of the peculiarities of these boilers is the small proportion of water-heating surface compared with the grate surface. The proportion is only 20.6 to 1. There is also nearly half as much steam-heating surface, the proportion being 9.3 to 1. The ratio of the sum of these is less than is found in most horizontal tubular boilers. To the low proportion of water surface is due, in a large degree, the high temperature of the escaping gases, with its attendant loss of heat and low rate of evaporation per pound of coal which the tests reveal. To the large proportion of steam-heating surface is due the large amount of superheating which this type of boiler gives.

The evaporative results include no allowance for the superheated condition of the steam. An intelligent view of the work of the boilers cannot be had without taking the superheating into account. What allowance should be made for a given number of degrees of superheat depends somewhat upon the character of the work. The added value of the superheated steam is never less than the equivalent of the excess of heat which it possesses over saturated steam, whatever the use to which it is applied. But for working engines, its added value is greater than this equivalent. If the added heat is one per cent. the added value for power is in round numbers two per cent. Applying an allowance of double the added heat to the figures obtained on the second test (test No. 24) the result becomes 10.32 pounds of water from and at 212 degrees per pound of combustible. This figure is inferior to the results obtained from horizontal boilers of good performance.

The two tests here reported show the unfavorable effect produced upon this type of boiler by a high rate of combustion and excessive capacity. The quantity of coal burned in a given time in test No. 23 was 54 per cent. larger than in test No. 24, and the evaporation per pound of coal was reduced 14.4 per cent. This reduction is accounted for by the increased temperature of the escaping gases, which was from 480 degrees to 600 degrees. The amount of power developed on the capacity test was large, and the ease here shown with which the vertical boiler generates steam should not be lost sight of. With a stack only 60 feet high, the boilers developed 21 per cent. more than the rated capacity (without allowance for the greater efficiency of superheated steam), and the rate of combustion was 17.1 pounds of coal per square foot of grate per hour.

BOILER No. 13.

Kind of boiler, ...	Vertical tubular (rolling-pin).
Number used, ...	One.
Horse-power (basis 10 square feet), .	One hundred and forty.
Kind of coal, ...	Delaware and Lackawanna, Anthracite, Broken.
Age, ...	Ten years.

Dimensions.

Diameter of main shell,	90 in.
Diameter of drum and water leg,	29 in.
Length of main shell and tubes,	9 ft. 9 in.
Number of tubes 2 inches outside diameter,	248
Area of water-heating surface,	1,159 sq. ft.
Area of steam-heating surface,	208 sq. ft.
Area of total heating surface,	1,367 sq. ft.
Area of grate surface,	45.7 sq. ft.
Area through tubes,	4.1 sq. ft.
Width of air spaces and metal bars in grates,	3-8 in.
Area through stack,	8.7 sq. ft.
Height of stack,	60 ft.
Ratio of water-heating surface to grate surface,	25.4 to 1
Ratio of steam-heating surface to grate surface,	4.6 to 1
Ratio of total heating surface to grate surface,	30 to 1
Ratio of grate to tube area,	11 to 1
Kind of brick setting,	Common.

Results of Test.

	Test No. 25.
Manner of start and stop and kind of run,	Ordinary.
Duration,	11.7 hrs.
Coal consumed (including wood equivalent),	5,897 lbs.
Percentage of ash,	8.4 %
Water evaporated,	48,735 lbs.
Coal per hour,	504 lbs.
Coal per hour per square foot of grate,	11 lbs.
Water per hour,	4,165.4 lbs.
Water per hour per square foot of water-heating surface,	3.6 lbs.
Horse-power developed,	134.8 H. P.
Boiler pressure,	80 lbs.
Temperature of feed-water,	134 deg.
Temperature of escaping gases,	434 deg.
Number of degrees of superheating,	14 deg.
Water per pound of coal,	8.26 lbs.
Water per pound of coal from and at 212 degrees,	9.22 lbs.
Water per pound of combustible from and at 212 degrees,	10.07 lbs.

Boiler No. 13 does not differ from the preceding one (boiler No. 12) excepting in the proportion which exists between the water and steam surfaces. It has 4.8 square feet more water-

heating surface and the same amount less steam-heating surface for each square foot of grate than the other boiler.

Comparing the results produced in the two cases, it appears that there is a marked difference in the number of degrees of superheating. The superheating is 90 degrees in one case and only 14 degrees in the other. The temperature of the waste gases has fallen from 480 degrees to 434 degrees. The water evaporated per pound of coal from and at 212 degrees is increased from 8.75 pounds to 9.22 pounds, or 5 per cent. If an allowance is made for superheating according to the quantity of heat added, the results become respectively 9.10 pounds and 9.29 pounds. The increased water-heating surface, therefore, secured an increase of 2 per cent. in the amount of heat derived from the coal. On the whole, then, the gain in evaporation is largely counterbalanced by the loss of superheating, and the net economical result appears to be about the same in both cases.

Boiler No. 14.

Kind of boilers,	Horizontal return tubular.
Number used,	Six.
Horse-power (collective, basis 12 sq. ft.),	Four hundred and seventy.
Kind of coal,	Anthracite Screenings 3 parts, Cumberland Bituminous 1 part.
Age,	Five months.

Dimensions.

Diameter of each shell,	60	in.
Length between heads and length of tubes,	15	ft.
Number of tubes (collective) 3 1-2 inches outside diameter,	348	
Area of heating surface,	5,646	sq. ft.
Area of grate surface,	150	sq. ft.
Area through tubes,	20	sq. ft.
Height of chimney,	150	ft.
Width of air spaces and metal bars in grates,	3-8	in.
Ratio of heating surface to grate surface,	37.6	to 1
Ratio of grate surface to tube area,	7.5	to 1
Kind of brick setting,	Passages in walls supplying air to sides of furnace and top of bridge wall.	

Results of Test. (Two days.)

	Test No. 26.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	13.5	hrs.
Coal consumed dry (including wood equivalent),	20,476	lbs.
Percentage of ash,	14.2	%
Water evaporated,	163,705	lbs.
Coal per hour,	1,516.7	lbs.
Coal per hour per square foot of grate,	10.1	lbs.
Water per hour,	12,125.9	lbs.
Water per hour per square foot of heating surface,	2.1	lbs.
Horse-power developed,	404.2	H. P.
Boiler pressure,	86	lbs.
Temperature of feed-water,	102	deg.
Temperature of escaping gases,	410	deg.
Water per pound of coal,	7.99	lbs.
Water per pound of coal from and at 212 degrees,	9.18	lbs.
Water per pound of combustible from and at 212 degrees,	10.70	lbs.

NOTE. — The coal when fired contained 5 per cent. of water.

Boiler No. 14 differs but little from the ordinary form of horizontal tubular boilers. The air passages in the walls are supplied through pipes laid in the flue, which present about 3 per cent. as much surface to the heat of the gases as the area of heating surface in the boilers.

The results furnish an indication of the performance of a cheap grade of fuel in a furnace which is claimed to be specially adapted for economical work.

There is not much satisfaction in comparing the results obtained on different boilers where inferior grades of coal are used, for the reason that such fuels vary much in quality. Compare, for example, the figures obtained on this test with those on test No. 18, boiler No. 9. There is an apparent advantage of this boiler over the other of about 15 per cent., although this one used a fuel containing a weaker proportion of bituminous coal. Examination, however, reveals the fact that in the test No. 18, supposing the Cumberland coal contained 7 per cent. of ash, the screenings contained 28 per cent., and in the test under consideration (test No. 26), supposing the same ash in the Cumberland coal, the screenings contained only 16 per cent. of ash.

Boiler No. 15.

Kind of boiler,	Vertical tubular with fire-box.
Number used,	One.
Horse-power (basis 10 square feet),	Twenty.
Kind of coal,	Anthracite Lehigh, Egg.
Age,	Four months.

Dimensions.

Diameter of shell,	40	in.
Diameter of fire-box and grate,	33	in.
Height between heads and length of tubes,	9 ft. 6 in.	
Number of tubes 2 inches outside diameter,	42	
Height of fire-box,	24	in.
Area of heating surface (total),	205	sq. ft.
Area of grate surface,	6.1	sq. ft.
Area through tubes,	0.7	sq. ft.
Area through stack,	0.78	sq. ft.
Height of stack,	52	ft
Ratio of total heating surface to grate surface,	33.5	to 1
Ratio of grate surface to tube area,	8.7	to 1

Results of Tests.

		Test No. 27.	Test No. 28.
Manner of start and stop,		Ordinary with preliminary heating.	Ordinary with preliminary heating.
Kind of run,		Continuous.	Continuous.
Duration,	hrs.	7.25	7.25
Coal consumed (including wood equivalent),	lbs.	664	404
Percentage of ash,	%	8.9	9.4
Water evaporated,	lbs.	5,676	3,597
Coal per hour,	lbs.	91.6	55.8
Coal per hour per square foot of grate,	lbs.	15	9.1
Water per hour,	lbs.	782.9	496.2
Water per hour per square foot of total heating surface,	lbs.	3 8	2.42
Horse-power developed,	H. P.	24.5	15.5
Boiler pressure,	lbs.	89	91
Temperature of feed-water,	deg.	163	182
Temperature of escaping gases,	deg.	596	446
Water per pound of coal,	lbs.	8.55	8.90
Water per pound of coal from and at 212 degrees,	lbs.	9.30	9.52
Water per pound of combustible from and at 212 degrees,	lbs.	10.22	10.51

Boiler No. 15 is so arranged that the steam, after being discharged from the steam space, passes into a drum which is connected with the shell in such a manner that the superheat is absorbed by the water and the steam leaves the boiler in a saturated state. Twenty per cent. of the total surface was not covered with water, but, owing to this provision, its superheating effect was practically nullified. The outside of the shell was protected by non-conducting covering. The stack was placed directly above the boiler, being supported by the upper tube sheet. The position of the stack interfered with cleaning the tubes, and as a consequence they had not been brushed out since the boiler was started four months before.

These tests are of interest in showing what may be expected from a small vertical boiler which was comparatively new, but which had not received special care to keep it clean. One thing is noticeable, and that is the rapid evaporation per square foot of heating surface and the high rate of combustion for a low stack, and still the boiler was worked at less than its maximum capacity. The vertical type of boiler, with stack directly above it, is favorable for the production of large capacity with a feeble draught, for there is no hindrance to the natural upward current of the products of combustion. The high temperature of the waste gases is a feature in test No. 27, and this is doubtless the cause of the relatively low evaporative result obtained on that test. An evaporation of 10.22 pounds of water per pound of combustible from and at 212 degrees, however, for a small boiler must be considered under the circumstances an excellent result.

The difference in the results of the two tests, in one of which the capacity was 65 per cent. greater than in the other, is not very marked. There is a large difference in the waste heat, but evidently the loss at the furnace from lower furnace temperature largely offsets the gain at the chimney from the lower temperature of the escaping gases.

Boiler No. 16.

Kind of boiler,	"Double-deck," hor. ret. tub.
Number used,	One.
Horse-power (basis 15 square feet),	One hundred and fifty.
Kind of coal,	Delaware and Lackawanna, Anthracite, Broken.
Age,	New.

Dimensions.

Diameter of lower shell,	66	in.
Diameter of upper shell,	36	in.
Length of shells and tubes,	15	ft.
Number of tubes 3 inches outside diameter,	172	
Area of water-heating surface,	2,235	sq. ft.
Area of steam-heating surface,	70	sq. ft.
Area through tubes,	7.1	sq. ft.
Area of grate surface,	36.6	sq. ft.
Width of air spaces and metal bars in grates,	Air 5-8 in., metal 1-2 in.	
Ratio of water-heating surface to grate surface,	60.9	to 1
Ratio of steam-heating surface to grate surface,	2	to 1
Ratio of grate to tube area,	5.2	to 1
Kind of brick setting,	Common.	

Results of Test. (Average of two.)

	Test No. 29.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	11.7	hrs.
Coal consumed (including wood equivalent),	6,237	lbs.
Percentage of ash,	8.1	%
Water evaporated,	56,388	lbs.
Coal per hour,	530.8	lbs.
Coal per hour per square foot of grate,	14.5	lbs.
Water per hour,	4,799	lbs.
Water per hour per square foot of water-heating surface,	2.1	lbs.
Horse-power developed,	155.1	H. P.
Boiler pressure,	79	lbs.
Temperature of feed-water,	132	deg.
Temperature of escaping gases,	373	deg.
Percentage of moisture in steam,	0.3	%
Water per pound of coal,	9.04	lbs.
Water per pound of coal from and at 212 degrees,	9.76	lbs.
Water per pound of combustible from and at 212 degrees,	11.00	lbs.

Boiler No. 16 is similar to No. 11 and others already referred to of the double-deck type.

The results obtained on test No. 29 show a good degree of economy, but they are not superior to those obtained in numerous cases from horizontal tubular boilers of the ordinary type containing a much less area of heating surface. On account of the large area of the tube opening compared with grate surface, elsewhere noted, the heating surface is to some extent inefficient. The tests were made with dampers wide open. The chimney was of ample area and 70 feet in height.

The horse-power developed was somewhat in excess of the nominal power. It appears, however, that the capacity was not sufficiently in excess of the nominal to make the boiler capable of maintaining its nominal power in the exigencies of ordinary work, without the most careful attention on the part of the fireman.

Boiler No. 17.

Kind of boiler,	Horizontal tubular.
Number used,	One.
Horse-power (basis 12 square feet),	One hundred.
Kind of coal,	Anthracite Pea and Dust 3 parts, George's Creek Cumberland 1 part.
Age,	New.

Dimensions.

Diameter of shell,	72	in.
Length between heads and length of tubes,	15	ft.
Number of tubes 4 inches outside diameter,	70	
Area of heating surface,	1,189	sq. ft.
Area of grate surface,	36	sq. ft.
Area through tubes,	5.3	sq. ft.
Area through chimney,	5.9	sq. ft.
Height of chimney,	60	ft.
Width of air spaces and metal bars in grates,	Air 7-16 in., metal 3-8 in.	
Ratio of heating surface to grate surface,	33	to 1
Ratio of grate surface to tube area,	6.7	to 1
Kind of brick setting,	Detached furnace, forced draught.	

Results of Tests.

		Test No. 30.	Test No. 31.
Conditions as to draught,		Natural draft.	Forced draft.
Manner of start and stop,		Ordinary with preliminary heating.	Ordinary with preliminary heating.
Kind of run,		Continuous.	Continuous.
Duration,	hrs.	7.2	7.5
Coal consumed dry (including wood equivalent),	lbs.	2,750	3,430
Percentage of ash,	%	11	9.6
Water evaporated,	lbs.	21,876	27,869
Coal per hour,	lbs.	379.4	457.4
Coal per hour per square foot of grate,	lbs.	10.5	12.7
Water per hour,	lbs.	3,017.4	3,715.9
Water per hour per square foot heating surface,	lbs.	2.5	3.1
Horse-power developed,	H. P.	105.6	130
Boiler pressure,	lbs.	70	71
Temperature of feed-water,	deg.	51	52
Temperature of escaping gases,	deg.	395	400
Water per pound of coal,	lbs.	7.95	8.12
Water per pound of coal from and at 212 degrees,	lbs.	9.54	9.74
Water per pound of combustible from and at 212 degrees,	lbs.	10.73	10.79

NOTE.—The coal was wet before firing, and the weight was increased by this means about 6 per cent.

Boiler No. 17 has the same general arrangement of the furnace with reference to the tube surface as the locomotive type of boiler. The products of combustion, after passing forward through the tubes, return beneath the shell and enter the chimney from the front end. The forced draught is secured by a fan which discharges the blast under the grates. The blast is in a measure a warm blast, the air first passing through a pipe in the flue, whose heating surface amounts to 15 per cent. of the area of heating surface in the boilers. The temperature of the air supplied for combustion was by this means increased from 30 degrees to 50 degrees.

These tests furnish a comparison between the use of natural

draught and forced draught, in a case where the fuel was largely composed of anthracite screenings. The boiler worked to fully its rated power on the natural draught test and to 25 per cent. higher rate on the forced draught test, and here the conditions are not precisely the same. There is a slight gain, amounting to 2 per cent., shown in favor of the forced draught, when figured on the evaporation per pound of coal, but the results are practically identical when figured on combustible. There appears on the whole to be no marked gain in favor of either method, and the question arises whether this goes to show that the heating of the air in the case of the forced draught test was ineffective, or whether this heating was beneficial and the gain which it produced was offset by loss due to forced draught. With forced draught there is a chance for loss from excessive supply of air at times when the bed of coal is allowed to become too thin, or when it burns through to the grate. Loss may occur from this cause whatever the nature of the draught, but it is liable to be greater in the case of forced draught on account of the greater quantity and force of air which is supplied. For this reason the results obtained with natural draught, under ordinary conditions, would be expected to be better than those obtained with forced draught.

The unusually low percentage of ash for this grade of fuel indicates that the coal was of excellent quality. It would be reasonable to expect, then, unusually high efficiency. There is nothing unusual, however, in the general character of the results, and the conclusion may be drawn that the use of a detached furnace is not advantageous. One source of loss in this arrangement, which may be of a serious nature, is the radiation of heat from the top and sides of the furnace. The inside of the furnace is necessarily heated to a high degree, and there is much greater liability to loss from external radiation than in the case of the ordinary method of setting. In the ordinary case the temperature is kept down by the comparatively large extent of boiler surface in the more immediate neighborhood of the fuel.

A subsequent test was made, using screenings alone and

forced draught (the screenings being wet 7 per cent. before firing). The percentage of ash was 15 per cent.; the horse-power developed was the same as in test No. 30; the temperature of the escaping gases 356 degrees (39 degrees lower than that of test No. 30). The evaporation from and at 212 degrees was 8.17 pounds per pound of coal and 9.63 pounds per pound of combustible. It is not certain that the screenings here used were of the same quality (though of the same name) as those used in the mixture tests; nevertheless, a large gain appears to have been produced by the introduction of 25 per cent. of Cumberland coal. The increase, figured upon combustible, is about 11 per cent.

BOILER No. 18.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Seventy-four.
Age,	Two months.

Dimensions.

Diameter of each shell,	60 in.
Length between heads and length of tubes,	15 ft.
Number of tubes 3 inches outside diameter,	66
Area of heating surface,	890 sq. ft.
Area of grate surface,	25.7 sq. ft.
Area through tubes,	2.7 sq. ft.
Area through chimney,	7 sq. ft.
Height of chimney,	90 ft.
Width of air spaces and metal bars in grates,	Air 3-8 in., metal 1-2 in.
Distance of grate to shell,	26 in.
Distance of flat bridge wall to shell,	9 in.
Character of space behind bridge wall,	Partially filled, inclined covering.
Ratio of heating surface to grate surface,	34.6 to 1
Ratio of grate surface to tube area,	9.4 to 1
Kind of brick setting,	Common, with air admitted at bridge wall.

Results of Tests.

	Test No. 32.	Test No. 33.	Test No. 34.
Kind of coal,	George's Creek Cumberland, Bituminous.	Lehigh Egg, Anthracite.	Equal parts Anthracite Screenings, & Cumberl'd.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.	Ordinary.
Duration, ... hrs.	14	17.5	14.5
Coal consumed dry (including wood equivalent), ... lbs.	6,559	6,309	5,102
Percentage of ash, ... %	6.6	9.4	13.5
Water evaporated, ... lbs.	56,555	53,153	39,658
Coal per hour, ... lbs.	498.5	360.5	351.9
Coal per hour per sq. ft. of grate, . lbs.	18.2	14	13.7
Water per hour, ... lbs.	4,039.7	3,037.3	2,735.1
Water per hour per square foot of heating surface, ... lbs.	4.5	3.4	3.1
Horse-power developed, . . H. P.	143.8	105.5	95.1
Boiler pressure, ... lbs.	66	62	65
Temperature of feed-water, . . deg.	40	40	42
Temperature of escaping gases, . deg.	453	349	343
Percentage of moisture in steam, . %	0.3	–	–
Water per pound of coal, . . lbs.	8.62	8.42	7.77
Water per pound of coal from and at 212 degrees, ... lbs.	10.43	10.18	9.39
Water per pound of combustible from and at 212 degrees, . . lbs.	11.17	11.24	10.85

Boiler No. 18 is unlike the ordinary horizontal tubular boiler in being provided with a water leg which forms the front wall of the furnace. This feature, however, does not change the general character of the boiler. The air which is supplied to the bridge wall enters directly from the outside, and discharges through perforated spherical iron surfaces at the bridge wall which are exposed to the products of combustion as they leave the furnace. The quantity of air which would naturally enter by the action of the draught is increased by means of a jet of steam which discharges into the supply pipe, and the steam thus used mingles with the air and enters the furnace along with it.

The results of the tests are chiefly interesting since they show the quantity of power that can be obtained from a boiler of the horizontal return tubular form, using various kinds of

coal. The chimney gave a draught corresponding to three-eighths of an inch water pressure, and the damper was carried wide open on all the tests, so as to secure its full capacity. Moreover, the fires were well tended so that they should do their maximum work, being frequently broken up and sliced, not only when the bituminous coals were burned, but also when anthracite coal was burned. Under these conditions the developed power, when Cumberland coal was used, was nearly two times the rated power; when Anthracite Lehigh was used it was nearly 50 per cent. larger, and when the mixture of equal parts of Screenings and Cumberland coal was burned it was nearly one-third larger. Compared among themselves the Cumberland coal developed 36 per cent. more power than the Anthracite coal and 50 per cent. more power than the mixture. These are valuable indications of the relative capacity of the different fuels named.

As to economy the fuels cannot fairly be compared, because so much difference exists in the amount of power developed, especially in the case of the Cumberland coal. A high degree of economy is shown in the case of the Anthracite coal, considering the large power developed. The rate of combustion is 14 pounds per square foot of grate per hour, and this is high. The temperature of the escaping gases is 349 degrees, and this is low. These are two vital elements which enter into the conditions favoring economy.

A subsequent test was made to determine the effect produced upon the economy of the boiler by dispensing with the admission of air at the bridge wall. The test was made when using Cumberland coal, and the principal results obtained were as follows: —

Coal per hour per square foot of grate,	18.8	lbs.
Percentage of ash,	7	%
Horse-power developed,	135	H. P.
Temperature of feed-water,	40	deg.
Temperature of escaping gases,	486	deg.
Water per pound of coal,	7.94	lbs.
Water per pound of coal from and at 212 degrees,	9.62	lbs.
Water per pound of combustible from and at 212 degrees,	10.34	lbs.

The disuse of air at the bridge wall produced a marked effect upon the economy. The evaporation per pound of coal was reduced nearly 8 per cent.

An interesting feature in these results appears in the gain which occurred in the temperature of the escaping gases. The exclusion of the air was attended by an increase in this temperature of 33 degrees.

BOILER NO. 19.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Fifty-five.
Kind of coal,	Anthracite Lehigh, Broken.
Age,	Several years.

Dimensions.

Diameter of each shell,	48	in.
Length between heads and length of tubes,	16	ft.
Number of tubes 3 inches outside diameter,	48	
Area of water-heating surface,	656	sq. ft.
Area of steam-heating surface,	80	sq. ft.
Area of grate surface,	19.5	sq. ft.
Area through tubes,	2	sq. ft.
Width of air spaces and metal bars in grates,	3-8	in.
Distance of grate to shell,	24	in.
Distance of curved bridge wall to shell,	8	in.
Character of space behind bridge wall,	Filled.	
Ratio of water-heating surface to grate surface,	33.5	to 1
Ratio of steam-heating surface to grate surface,	4.1	to 1
Ratio of grate to tube area,	9.7	to 1
Kind of brick setting,	Common.	

Results of Tests.

		Test No. 35.	Test No. 36.
Conditions,		Hand regulation of draught.	Automatic regulation of draught.
Manner of start and stop,		Ordinary.	Ordinary.
Kind of run,		Continuous.	Continuous.
Duration,	hrs.	10.2	10
Coal consumed (including wood equivalent),	lbs.	937	980
Percentage of ash,	%	13.1	14.1
Water evaporated,	lbs.	8,638	9,263
Coal per hour,	lbs.	91.9	91.3
Coal per hour per sq. ft. of grate,	lbs.	4.7	4.7
Water per hour,	lbs.	846.9	926.3
Water per hour per square foot water-heating surface,	lbs.	1.3	1.4
Horse-power developed,	H. P.	25.1	27.8
Boiler pressure,	lbs.	46	47
Temperature of feed-water,	deg.	200	200
Temperature of escaping gases,	deg.	297	299
Water per pound of coal,	lbs.	9.22	9.45
Water per pound of coal from and at 212 degrees,	lbs.	9.57	9.81
Water per pound of combustible from and at 212 degrees,	lbs.	11.01	11.42

Boiler No. 19 has a flue which carries the escaping gases over the top of the shell, thus providing steam-heating surface. This surface, as elsewhere noted, is probably inefficient on account of the facility offered for the deposit of soot.

A comparison of tests Nos. 35 and 36 brings out the favorable effect produced by automatic regulation of the draught over hand regulation. It is a difficult matter to show by means of a test the economy produced by automatic regulation, there is so much depending upon the personal element in the case of the hand regulation. One method should produce the same result as the other, provided the person to whom the hand regulation is intrusted does the work with the same efficiency as that secured by the automatic device. These tests clearly reveal the fact that an unsteady draught, such as attends ineffi-

cient hand regulation, has a tendency to produce a lower measure of economy, though the actual amount of loss may vary a large amount. Tests on other plants gave a result in some cases favorable to automatic regulation, and in some cases favorable to hand regulation. It may be said that the hand regulation which occurs during the unusual state of things which accompanies an evaporative test, when the fireman may perhaps have an incentive to do his best, is a different thing from the hand regulation which would obtain in the common work of firing.

These tests show the performance of a small-sized horizontal return tubular boiler which was in good condition, though having been a number of years in use, and which was fired with an excellent grade of anthracite coal. The boiler was worked at low capacity, but this did not seem to reduce the economy to any great extent, for a subsequent test, made under conditions of automatic regulation of the draught, when the rate of combustion was 8.8 pounds of coal per square foot of grate per hour, the horse-power 49.3, and the temperature of the escaping gases 340 degrees, gave an evaporation of 11.62 pounds of water from and at 212 degrees per pound of combustible.

Boiler No. 20.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Fifty-three.
Age,	Several years.

Dimensions.

Diameter of shell,	48	in.
Length between heads and length of tubes,	15	ft.
Number of tubes 3 inches outside diameter,	49	
Area of heating surface,	639	sq. ft.
Area of grate surface,	18	sq. ft.
Area through tubes,	2	sq. ft.
Ratio of heating surface to grate surface,	35.5	to 1
Ratio of grate to tube area,	8.9	to 1
Kind of setting for coal,	Common.	

Results of Tests.

	Test No. 37.	Test No. 38.
Kind of fuel,	Anthracite, Broken.	Petroleum Oil.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.
Duration, ... hrs.	10	10
Fuel consumed, ... lbs.	986	1,365
Percentage of ash in coal, . . . %	15	–
Water evaporated, ... lbs.	8,493	15,787
Fuel per hour, ... lbs.	98.6	136.5
Fuel per hour per square foot of grate, lbs.	5.7	–
Water per hour, ... lbs.	849.3	1,578.7
Water per hour per square foot of heating surface, ... lbs.	1.3	2.5
Horse-power developed, . . H. P.	25.5	47.4
Boiler pressure, ... lbs.	59	62
Temperature of feed-water, . . deg.	208	208
Water per pound of fuel, ... lbs.	8.61	11.56
Water per pound of fuel from and at 212 degrees, ... lbs.	8.91	11.96
Water per pound of combustible from and at 212 degrees, ... lbs.	10.48	–

The tests on boiler No. 20 exhibit the performance of a crude petroleum oil, in comparison with anthracite coal. The apparatus used for burning the oil consisted of a burner to which the oil was brought by gravity, and from which it was injected into the furnace by means of a jet of superheated steam. The steam was derived from the boiler, and the superheat from a heater in the furnace. The grates commonly used were covered with bricks, and the air for combustion entered through the doorways of the furnace, the doors being removed. The space around the pipes connected with the apparatus, which passed through the doorways, was open. During the test the damper was wide open. The quantity of steam used in the burner amounted to 15 per cent. of the total generated by the boiler. The actual evaporation has been corrected for this quantity of steam, the record giving the net quantities.

The results of the tests show a higher evaporation per pound of fuel in the case of oil than in the case of coal, the increase

being 34.2 per cent. The quantity of fuel required to evaporate a given quantity of water — say 30,000 pounds — from and at 212 degrees in the two cases, according to these results, is 3,367 pounds or 1.5 tons of coal, and 2,509 pounds or 386 gallons of oil. The coal at $5 per ton costs $7.50. The price of oil per gallon required to make the total cost of oil a like amount is 1.9 cents. The employment of a liquid fuel serves to reduce to a minimum the labor attending the firing and care of a plant of boilers. A plant of 1,000 horse-power in a mill running 10 hours per day requires two firemen for day run, two helpers for wheeling coal, and one night hand for banking, removing ashes, and preparing the morning fires. The use of oil suitably arranged requires only one man, and dispenses with the labor of the remaining four. The saving in cost of labor thus realized represents about 10 per cent. of the cost of the fuel, when coal is $5 per ton and 12 tons of coal are burned per day. This element in the problem should not be disregarded when making a comparison of the relative economy of the two kinds of fuel. In the case of these tests it makes the price of oil for the plant noted 2.18 cents per gallon to equal the performance of coal at $5 per ton.

Boiler No. 21.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Sixty.
Kind of coal,	Anthracite Lehigh, Broken.

Dimensions.

Diameter of shell,	48	in.
Length between heads and length of tubes,	16	ft.
Number of tubes 3 inches outside diameter,	48	
Area of heating surface,	733	sq. ft.
Area of grate surface,	19.5	sq. ft.
Area through tubes,	2	sq. ft.
Ratio of heating surface to grate surface,	37.6	to 1
Ratio of grate surface to tube area,	9.7	to 1
Kind of brick setting,	Common.	

Results of Tests.

		Test No. 39.	Test No. 40.
Conditions,		Grates with 50 per cent. air space.	Grates with 60 per cent. air space.
Manner of start and stop,		Ordinary.	Ordinary.
Kind of run,		Continuous.	Continuous.
Duration,	hrs.	9.5	9.7
Coal consumed,	lbs.	1,623	1,643
Percentage of ash,	%	12.5	13.9
Water evaporated,	lbs.	15,935	15,597
Coal per hour,	lbs.	170.8	168.5
Coal per hour per square foot of grate,	lbs.	8.7	8.6
Water per hour,	lbs.	1,677.3	1,607.9
Water per hour per square foot of heating surface,	lbs.	2.3	2.3
Horse-power developed,	H. P.	50.3	48.2
Boiler pressure,	lbs.	47	46
Temperature of feed-water,	deg.	203	200
Temperature of escaping gases,	deg.	340	348
Water per pound of coal,	lbs.	9.83	9.49
Water per pound of coal from and at 212 degrees,	lbs.	10.17	9.85
Water per pound of combustible from and at 212 degrees,	lbs.	11.63	11.44

The tests on boiler No. 21 show the effect which the type of grates may have upon the economy. The principal difference in the two grates lay in the proportion of air space, in one of which it was 10 per cent. more than in the other. The grates with 50 per cent. air space evaporated about 2 per cent. more water per pound of combustible than those with 60 per cent. air space.

Similar tests were made to determine the effect produced with a much slower rate of combustion. Here the gain due to the smaller air space was 8 per cent. This shows that the slower the rate of combustion the smaller the amount of opening for draught should be through the grates. It is a little difficult to explain why this effect should be produced. The simplest explanation is that the large opening allows a much greater excess of air to enter the furnace than is admitted when

the opening is contracted. There is always an excess of air over that required for chemically perfect combustion, and this excess induces a loss. The greater the excess the greater the loss.

Boiler No. 22.

Kind of boiler,	Vertical tubular.
Number used,	One.
Horse-power (basis 10 square feet),	Seventy-five.
Age,	New.

Dimensions.

Diameter of shell,	64	in.
Height of shell and length of tubes,	14	ft.
Number of tubes 2 1-2 inches outside diameter,	88	
Diameter of brick furnace,	54	in.
Area of water-heating surface,	513	sq. ft.
Area of steam-heating surface,	248	sq. ft
Area of grate surface,	15.9	sq. ft.
Area through tubes,	2.4	sq. ft.
Width of air spaces and metal bars in grates,	Air 5-8 in., metal 3-4 in.	
Area through stack,	5.9	sq. ft.
Height of stack,	60	ft.
Distance from grate to tube sheet,	4	ft.
Ratio of water-heating surface to grate surface,	32.3	to 1
Ratio of steam-heating surface to grate surface,	15.6	to 1
Ratio of grate to tube area,	6.5	to 1

Results of Tests.

	Test No. 41.	Test No. 42.	Test No. 43.
Kind of coal,	Anthracite Schuylkill, Broken.	Anthracite Schuylkill, Broken.	Anthracite Schuylkill, Screenings.
Draught,	Natural.	Forced.	Forced.
Manner of start and stop,	Ordinary with preliminary heating.	Ordinary with preliminary heating.	Ordinary with preliminary heating.
Kind of run,	Continuous.	Continuous.	Continuous.
Duration, . hrs.	10	10.7	7.7
Coal consumed dry (including wood equivalent), . lbs.	2,452	4,134	3,010
Percentage of ash, %	11.6	13.6	13.4
Water evaporated, . lbs.	19,583	29,846	19,937
Coal per hour, . lbs.	245.2	384.5	392.4
Coal per hour per sq. ft. of grate, . lbs.	15.4	24.1	24.7
Water per hour, . lbs.	1,958.3	2,776.4	2,599.4
Water per hour per square foot of water-heating surface, . lbs.	3.8	5.4	5.1
Horse-power developed, . H. P.	64.3	91.2	85.4
Boiler pressure, . lbs.	61	73.2	73.1
Temperature of feed-water, . deg.	125	125	124
Temperature of escaping gases, . deg.	478	573	505
Number of degrees of superheating, deg.	42	59	51
Water per pound of coal, . lbs.	7.98	7.21	6.62
Water per pound of coal from and at 212 degrees, . lbs.	8.95	8.10	7.45
Water per pound of combustible from and at 212 degrees, . lbs.	10.13	9.38	8.61

Boiler No. 22 is provided with a brick furnace, and the outside of the shell is protected with a somewhat inefficient covering of cement.

The forced draught is produced by a fan which discharges into the ash-pit. The grates used for burning screenings are different from those used for the other fuels. A plate was employed which was perforated with half-inch holes, located 1½ inches from centre to centre.

The tubes of the boiler were not cleaned during the tests, and had not been cleaned since the boiler was started two weeks before.

The results of the tests show a low grade of economy, the cause of which is seen in the high temperature of escaping gases. This is due in part to the type of boiler and in part to

the evident dirty condition of the surfaces and to radiation from the shell.

The tests are chiefly interesting on account of the comparison which is afforded by the employment of a high rate of combustion with forced draught, and the use of screenings with a blast. The amount of power developed was increased by the use of the fan from 64.3 horse-power to 91.2 horse-power — an increase of 42 per cent. — and the effective evaporation per pound of coal was reduced 7.5 per cent. No allowance is here made for the cost of running the fan. The temperature of the escaping gases was increased 95 degrees by the increased rate of combustion, and the degree attained is very high and wasteful. Referring to tests Nos. 23 and 24, which were of a similar character, though made on a vertical boiler of quite different proportions, it is seen that the relation of water-heating surface to grate surface has an important bearing upon the economy of this type of boiler. In boiler No. 12, there referred to, the ratio is 20.6 to 1. In this boiler (boiler No. 22) it is 32.3 to 1. Here 40 per cent. higher rate of combustion is obtained, with a gain in evaporation per pound of combustible from and at 212 degrees (not allowing for superheating), from 8.18 pounds to 9.38 pounds, and this gain is evidently due, in a large measure, to the improved proportion of heating surface to grate surface.

The result obtained by the use of screenings is favorable when compared with those obtained with the standard anthracite coal. With the same rate of combustion, the evaporation with screenings is only 8 per cent. less than that with coal. The percentage of air space in the screenings grate was only 14 per cent., while that in the coal grate was 45 per cent. It is not improbable that the small space in the former produced a favorable result.

BOILER No. 23.

Kind of boiler, ...	Horizontal return tubular.
Number used, ...	One. .
Horse-power (basis 12 square feet), . .	Eighty-seven.
Age, ...	Eight months.

Dimensions.

Diameter of shell,	66	in.
Length of main shell between heads,	10	ft.
Number of tubes 3 inches outside diameter,	107	
Length of 52 tubes,	10	ft.
Length of 55 tubes,	13	ft.
Area of heating surface,	1,041	sq. ft.
Area of grate surface,	24.7	sq. ft.
Least area for draught through tubes,	2.1	sq. ft.
Area through chimney,	2.3	sq. ft.
Height of chimney,	95	ft.
Width of air spaces and metal bars in grates,	3-8	in.
Distance of grate to shell,	23	in.
Distance of bridge wall to shell,	7	in.
Ratio of heating surface to grate surface,	42	to 1
Ratio of grate to tube area,	11.6	to 1
Kind of brick setting,	Passages in walls supplying air to sides of furnace and bridge wall.	

Results of Tests.

		Test No. 44.	Test No. 45.	Test No. 46.	Test No. 47.
Kind of coal,		Lackawanna, Broken.	Lehigh, Broken.	George's Creek Cumberland.	2 pts. Screenings, 1 part. Geo.'s Creek Cumberland
Manner of start and stop and kind of run,		Ordinary.	Ordinary.	Ordinary.	Ordinary.
Duration,	hrs.	10.7	10.2	10.7	11.
Coal consumed dry (including wood equivalent),	lbs.	3,037	3,087	3,730	3,315
Percentage of ash,	%	12	10.1	6.6	16.5
Water evaporated,	lbs.	26,562	27,441	34,743	27,587
Coal per hour,	lbs.	282.5	301.2	347	301.4
Coal per hour per square foot of grate,	lbs.	11	12.2	14	12.2
Water per hour,	lbs.	2,470.9	2,677.2	3,231.9	2,507.9
Water per hour per square foot heating surface,	lbs.	2.4	2.6	3.1	2.4
Horse-power developed,	H. P.	79.5	88.5	105.4	82
Boiler pressure,	lbs.	70	76.6	77.6	76.1
Temperature of feed-water,	deg.	128	118	111	108
Temperature of escaping gases,	deg.	306	346	381	343
Draught suction,	in.	0.28	0.28	0.28	0.28
Water per pound of coal,	lbs.	8.75	8.89	9.31	8.32
Water per pound of coal from and at 212 degrees,	lbs.	9.80	10.07	10.61	9.51
Water per pound of combustible from and at 212 degrees,	lbs.	11.13	11.20	11.37	11.40

NOTE. — The mixed fuel when fired contained 5 per cent. of moisture.

Boiler No. 23 differs from the ordinary horizontal boiler in the arrangement of the tubes. Part of the tubes carry the products of combustion forward, as in the ordinary boiler; the remaining tubes carry them backward to the flue. The latter are placed centrally with reference to the former, and extend backward from the main tube sheet a distance of three feet, the extended portion being enclosed in a supplementary shell 34 inches in diameter, which forms an extension to the rear end of the boiler.

A prominent feature in the results of these tests is the comparatively low flue temperature. It may be attributed in part to the large extent of heating surface and in part to the particular arrangement of the tubes, which renders the heating surface more thoroughly efficient than it would otherwise be. The results are excellent in every case, excepting the test with Cumberland coal. Here the evaporation per pound of combustible is little better than that obtained with the anthracite coals and a trifle inferior to that obtained with the mixture. Figured on the weight of combustible used, there is a difference of only 2.5 per cent. in all the results. Figuring on coal, there is a gain for Lehigh coal of 2.8 per cent., a gain for Cumberland coal of 8.2 per cent., and a loss for the mixed fuel of 3 per cent., when compared with the result obtained from Lackawanna coal. The difference in these results seems to be mainly due to the difference in the percentages of ash.

The tests were made with wide open damper and a constant maximum draught. The figures of horse-power show the relative capacity of the boiler as produced by the various coals used. Lackawanna coal gave a trifle less than the rated power. Lehigh gained 11 per cent., Cumberland 33 per cent., and the mixture 3 per cent., over the Lackawanna.

The temperature of the escaping gases in the front connection, before passing into the central tubes, was 325 degrees higher than that in the flue at the entrance to the chimney.

Boiler No. 24.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Fifty-five.
Kind of coal,	Anthracite Lehigh, Chestnut.
Age,	Sixteen years.

Dimensions.

Diameter of shell,	48 in.
Length between heads and length of tubes,	16 ft.
Number of tubes 3 inches outside diameter,	48
Area of heating surface,	669 sq. ft.
Area of grate surface,	19.9 sq. ft.
Area through tubes,	2 sq. ft.
Area through flue,	1.9 sq. ft.
Height of chimney,	77 ft.
Width of air spaces and metal bars in grates,	Air 3-8 in., metal 5-8 in.
Distance of grate to shell,	19 in.
Distance of flat bridge wall to shell,	6 in.
Character of space behind bridge,	Open.
Ratio of heating surface to grate surface,	33.7 to 1
Ratio of grate to tube area,	10 to 1
Kind of brick setting,	Common.

Results of Tests.

	Test No. 48.	Test No. 49.
Conditions,	Damper wide open.	Damper partly open.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.
Duration, hrs.	11	11
Coal consumed (including wood equivalent), lbs.	2,647	1,430
Percentage of ash, %	16.4	17.5
Water evaporated, lbs.	19,653	10,731
Coal per hour, lbs.	240.6	130
Coal per hour per square foot of grate, lbs.	12.1	6.5
Water per hour, lbs.	1,786.6	975.6
Water per hour per square foot heating surface, lbs.	2.7	1.5
Horse-power developed, H. P.	62.1	33.9
Boiler pressure, lbs.	71.9	69.5
Temperature of feed-water, deg.	40	40
Temperature of escaping gases, deg.	444	356
Water per pound of coal, lbs.	7.42	7.50
Water per pound of coal from and at 212 degrees, lbs.	8.99	9.08
Water per pound of combustible from and at 212 degrees, lbs.	10.76	11.01

The tests on boiler No. 24 exhibit the performance of the boiler under two widely different rates of combustion. In one case the power developed was slightly above the nominal, and in the other it was much below it. The difference in the two results is only one per cent. on coal and two per cent. on combustible. The temperature of the escaping gases in the test with rapid combustion is somewhat excessive. There is evidence here of inefficient surface, such as might be produced by a coating of scale.

Boiler No. 25.

Kind of boiler,	Horizontal direct tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Fifty-two.
Kind of coal,	Anthracite Lehigh, Chestnut.
Age,	Fourteen years.

Dimensions.

Diameter of shell,	48	in.
Length between heads and length of tubes,	14	ft.
Number of tubes 3 inches outside diameter,	45	
Length of combustion chamber,	38	in.
Inside diameter of combustion chamber,	42	in.
Diameter two openings to combustion chamber,	14	in.
Area of water-heating surface,	586	sq. ft.
Area of steam-heating surface,	43	sq. ft.
Area of grate surface,	21.2	sq. ft.
Area through tubes,	1.9	sq. ft.
Area through flue,	2.2	sq. ft.
Width of air spaces and metal bars in grates,	Air 3-8 in., metal 5-8 in.	
Distance of grate to shell,	17	in.
Height of chimney,	77	ft.
Ratio of water-heating surface to grate surface,	27.7	to 1
Ratio of grate to tube area,	11.4	to 1
Kind of brick setting,	Common.	

Results of Tests.

	Test No. 50.	Test No. 51.
Conditions,	Damper wide open.	Damper partly closed.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.
Duration, ... hrs.	11.2	10.7
Coal consumed (including wood equivalent), ... lbs.	2,731	1,367.5
Percentage of ash, ... %	15.7	15.5
Water evaporated, ... lbs.	19,891	10,388
Coal per hour, ... lbs.	242.8	127.2
Coal per hour per square foot of grate, lbs.	11.4	6
Water per hour, ... lbs.	1,768.1	966.3
Water per hour per square foot of water-heating surface, ... lbs.	3	1.6
Horse-power developed, . . H. P.	61.4	33.5
Boiler pressure, ... lbs.	67.7	65.2
Temperature of feed-water, . . deg.	40	40
Temperature of escaping gases, . . deg.	476	380
Water per pound of coal, ... lbs.	7.28	7.60
Water per pound of coal from and at 212 degrees, ... lbs.	8.82	9.19
Water per pound of combustible from and at 212 degrees, ... lbs.	10.46	10.88

In boiler No. 25 the products of combustion pass upward from the furnace into a combustion chamber situated in the front end of the shell, then forward through the tubes, then backward under the shell to the furnace wall, and finally upward through two side flues and over the top of the rear part of the shell to the chimney flue. The upper part of the shell last traversed furnishes steam-heating surface. This surface is probably inefficient, owing to the deposit of soot which naturally covers it. The boiler is fitted with a steam dome.

The tests made on boiler No. 25, like those made on No. 24, show the effect produced by different rates of combustion. In this case the difference is more marked than in the former case. Here the slow rate secured about 4 per cent. better result; but the slow rate developed much less than the

nominal power of the boiler — a condition of things which it would hardly pay to maintain on a large plant for permanent work.

It is apparent that the boiler was wasteful on the test with rapid combustion, for the temperature of the gases is 476 degrees. There is more heat lost here than in the case of boiler No. 24, where the temperature is 444 degrees with a somewhat higher rate of combustion, and it is seen that there is a corresponding falling off in economy between the two boilers. This might be expected from the smaller proportion of water-heating surface. The proportions are, respectively, 33.7 to 1 and 27.7 to 1.

Boiler No. 26.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Seventy-four.
Kind of coal,	Anthracite Lehigh, Chestnut.
Age,	One year.

Dimensions.

Diameter of shell,	60	in.
Length between heads and length of tubes,	15	ft.
Number of tubes 3 inches outside diameter,	66	
Area of heating surface,	890	sq. ft.
Area of grate surface,	24.1	sq. ft.
Area through tubes,	2.7	sq. ft.
Area through flue,	2.4	sq. ft.
Height of chimney,	77	ft.
Width of air spaces and metal bars in grates,	Air 3-8 in., metal 5-8 in.	
Distance of grate to shell,	23	in.
Distance of flat bridge wall to shell,	7	in.
Character of space behind bridge wall,	Open.	
Ratio of heating surface to grate surface,	37	to 1
Ratio of grate to tube area,	10	to 1
Kind of brick setting,	Common.	

Results of Tests.

		Test No. 32.	Test No. 33.
Conditions,		Damper wide open.	Damper partly closed.
Manner of start and stop and kind of run,		Ordinary.	Ordinary.
Duration,	hrs.	12	11
Coal consumed (including wood equivalent),	lbs.	4,099	2,659
Percentage of ash,	%	14.4	14.2
Water evaporated,	lbs.	30,326	20,244
Coal per hour,	lbs.	341.6	241.7
Coal per hour per sq. ft. of grate,	lbs.	14.2	10
Water per hour,	lbs.	2,527.2	1,840.4
Water per hour per square foot heating surface,	lbs.	2.8	2.1
Horse-power developed,	H. P.	87.8	64
Boiler pressure,	lbs.	73.8	70
Temperature of feed-water,	deg.	40	40
Temperature of escaping gases,	deg.	365	350
Water per pound of coal,	lbs.	7.40	7.61
Water per pound of coal from and at 212 degrees,	lbs.	8.97	9.22
Water per pound of combustible from and at 212 degrees,	lbs.	10.47	10.75

Boiler No. 26 is provided with a water leg front, which takes the place of the ordinary cast-iron front and its brick lining. The space behind the bridge wall is unusually deep, extending a distance of seven feet below the shell, and one of the side walls is exposed on the outside a corresponding distance.

These tests, together with those made on boilers Nos. 24 and 25, form a group of tests, the object of which was to determine the relative economy of working to maximum capacity and to medium capacity, in the case of three boilers of somewhat different types. All used coal from the same cargo. In the case of boiler No. 26, as in those of Nos. 24 and 25 already noted, there is an appreciable difference of economy in favor of the medium capacity. Here it is about 3 per cent. There is a notably low temperature of the escaping gases compared with that found in the other two boilers worked at maximum

BOILER No. 26 — Continued.

Results of Tests.

		Test No. 54.	Test No. 55.	Test No. 56.	Test No. 57.	Test No. 58.
Kind of fuel,		Honeybrook Lehigh, Chestnut.	Honeybrook Lehigh, Pea.	Honeybrook Lehigh, Broken.	George's Creek Cumberland.*	Pea and Dust 2 pts., Cumberland 1 part.*
Manner of start and stop and kind of run,		Ordinary.	Ordinary.	Ordinary.	Ordinary.	Ordinary.
Duration,	hrs.	11	11	10.75	10.75	10.75
Coal consumed dry (including wood equivalent),	lbs.	2,659	2,869	3,419	2,369	2,792
Percentage of ash,	%	14.2	15.8	10.5	6.6	11.4
Water evaporated,	lbs.	20,244	19,919	27,089	21,520	22,537
Coal per hour,	lbs.	241.7	260.9	318	220.4	259.7
Coal per hour per square foot of grate,	lbs.	10	10.8	13.2	9.1	10.7
Water per hour,	lbs.	1,840.4	1,810.8	2,519.9	2,001.9	2,096.5
Water per hour per square foot of heating surface,	lbs.	2.1	2	2.8	2.2	2.4
Horse-power developed,	H. P.	64	62.8	87.7	69.6	72.9
Boiler pressure,	lbs.	70	70	72.6	69.9	71.6
Temperature of feed-water,	deg.	40	40	39	39	39
Temperature of escaping gases,	deg.	350	348	372	387	387
Water per pound of coal,	lbs.	7.61	6.94	7.92	9.08	8.07
Water per pound of coal from and at 212 degrees,	lbs.	9.22	8.40	9.61	11.00	9.79
Water per pound of combustible from and at 212 degrees,	lbs.	10.75	9.98	10.74	11.78	11.06

* These coals were moist when fired.

capacity, due, no doubt, in part, to the relatively large extent of heating surface, and in part to the cleanliness of the surfaces which presumably existed in the new boiler. Still, this favorable indication is accompanied by a comparatively low evaporative result. The large space behind the bridge and the greater radiating surfaces thus exposed does not appear to be adequate to produce an unfavorable effect of much consequence, but there appears no other cause. It is noted that a higher rate of combustion is secured in boiler No. 26 than in the others. This may be attributed to the newer and tighter condition of the flues leading to the chimney. One chimney of ample area served for all three boilers.

The object of tests Nos. 54–58 was to compare the evaporative economy of different fuels. The results do not show in point of capacity the full power that could have been obtained in the various cases, with the exception of the test of the mixed fuel, in which case the damper was wide open. The damper was wide open during half of the test of pea coal.

Taking the results with chestnut coal as a basis of comparison, and figuring on the evaporation per pound of coal, the pea coal lost 9 per cent.; the broken coal gained 4.2 per cent.; the Cumberland coal gained 19.3 per cent.; and the mixed fuel gained 6.2 per cent.

Considering the cost of these fuels given below, as quoted at the time of the tests (per ton of 2,240 pounds),

Chestnut,	$5.50
Pea,	4.60
Broken,	5.85
Pea and Dust,	2.75
Cumberland,	6.50

the total value of the fuel used in evaporating a given quantity of water, say 30,000 pounds from and at 212 degrees, according to the results here obtained, is as follows: —

Chestnut,	$8.00
Pea,	7.32
Broken,	8.15
Cumberland,	7.91
Mixed fuel,	5.48

Boiler No. 26 — Concluded.

Results of Tests.

	Test No. 59.	Test No. 60.	Test No. 61.	Test No. 62.	Test No. 63.	Test No. 64.
Kind of coal,	Cumberland, George's Creek.*	Cumberland, George's Creek.*	Pea and Dust 2 parts, Cumberland 1 part.*	Pea and Dust 2 parts, Cumberland 1 part.*	Anthracite Lehigh, Broken.	Anthracite Lehigh, Broken.
Conditions as to admission of air at bridge wall,	Air admitted.	No air admitted.	Air admitted.	No air admitted.	Air admitted.	No air admitted.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.	Ordinary.	Ordinary.	Ordinary.	Ordinary.
Duration, ... hrs.	10.75	10.75	10.75	11	11	10.75
Coal consumed dry (including wood equivalent), ... lbs.	2,369	2,556	2,792	2,874	3,236	3,419
Percentage of ash, ... %	6.6	6.4	11.4	13.8	10	10.5
Water evaporated, ... lbs.	21,520	21,892	22,537	23,685	25,597	27,089
Coal per hour, ... lbs.	220.4	237.3	259.7	261.3	294.2	318
Coal per hour per square foot of grate, . lbs.	9.1	9.4	10.7	10.8	12.2	13.2
Water per hour, ... lbs.	2,001.9	2,036.5	2,096.5	2,153.2	2,327	2,519.9
Water per hour per square foot heating surface, ... lbs.	2.2	2.3	2.4	2.4	2.6	2.8
Horse-power developed, ... H. P.	69.6	70.8	72.9	74.8	81.9	87.7
Boiler pressure, ... lbs.	69.9	68.1	71.6	72	68.2	72.6
Temperature of feed-water, ... deg.	39	39	39	39	39	39
Temperature of escaping gases, . . deg.	387	372	387	362	389	372
Water per pound of coal, ... lbs.	9.08	8.57	8.07	8.24	7.91	7.92
Water per pound of coal from and at 212 degrees, ... lbs.	11.00	10.39	9.79	9.99	9.59	9.61
Water per pound of combustible from and at 212 degrees, ... lbs.	11.78	11.09	11.06	11.60	10.65	10.74

* These coals were moist when fired.

According to this basis of comparison, which may be called the commercial basis, the cost with pea coal is reduced $0.32, or 8.5 per cent.; that with broken coal is increased $0.15, or 1.9 per cent.; that with Cumberland is reduced $0.09, or 1.1 per cent.; and that with the mixture is reduced $2.52, or 31.5 per cent. Although this comparison does not apply to the present time, when prices of coal are altogether different, the figures are suggestive as to the influence which cost has upon the actual value of a given kind of coal.

A feature of this series of tests which attracts attention is the varying amount of ash in the different fuels. The pea coal has the largest quantity, viz., 15.8 per cent., and the Cumberland the smallest, viz., 6.6 per cent. The percentage in the mixed fuel is low for this class of fuel — an indication of good quality.

The temperature of the escaping gases in the case of the Cumberland and mixed fuels is higher than that produced by the other coals. This condition is almost always observed in fuels made up in whole or in part of bituminous coal.

The object of tests Nos. 59–64 was to determine the effect upon the economy of different fuels produced by admitting air at the bridge wall. The method employed in supplying air consisted in introducing it through a pipe 7 inches in diameter running through the side wall, at a distance of 26 inches below the top of the bridge wall. The pipe entered a chamber formed by building a new wall a few inches behind the bridge and covering the top of the intervening space with a perforated iron plate, which was placed on a level with the top of the bridge. A damper was provided in the pipe, and was wide open when Cumberland coal was used and about half-way open with the other fuels.

The effect upon the economic result produced by the admission of air at the bridge was marked in the case of the Cumberland coal and mixed fuel, but not so in that of the anthracite coal. The evaporation per pound of combustible was increased 6.2 per cent. with Cumberland coal, but it was decreased 4.7 per cent. with the mixed fuel. There was little difference produced with anthracite coal.

In every case the admission of air is accompanied by an increased temperature of the escaping gases and a decreased amount of power developed. These differences are small, but they are always in the same direction.

The character of the combustion, as seen by the eye of an observer looking through a peek hole into the space behind the bridge wall, was always improved by the admission of air.

The effect of admitting air upon the Cumberland coal was to reduce the quantity and density of the smoke discharged at the top of the chimney. There was entire absence of smoke $\frac{80}{100}$ of the time when air was admitted, and $\frac{26}{100}$ of the time when air was not admitted. There was little smoke in either case with mixed fuel.

There was no appreciable difference in the quantity of soot deposited in the tubes, as seen by examination at the front ends after each test, whether air was admitted at the bridge or not.

The draught suction at the bottom of the chimney was ordinarily $\frac{7}{16}$ of an inch, expressed in inches of water pressure. In the boiler flue it was $\frac{3}{8}$ of an inch with wide open damper, and in the space behind the bridge wall $\frac{3}{16}$ of an inch.

Boiler No. 27.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Seventy-five.
Age,	Two years.

Dimensions.

Diameter of shell,	60	in.
Length between heads and length of tubes,	15	ft.
Number of tubes 3 inches outside diameter,	70	
Area of heating surface,	900	sq. ft.
Area of grate surface,	26.7	sq. ft.
Area through tubes,	2.9	sq. ft.
Area through flue,	3	sq. ft.
Height of chimney,	120	ft.
Width of air spaces and metal bars in grates,	3-8	in.
Distance of grate to shell,	20	in.
Distance of flat bridge to shell,	6	in.

Character of space behind bridge, ...	Open.
Ratio of heating surface to grate surface, ...	33.8 to 1
Ratio of grate surface to tube area, ...	9.2 to 1
Kind of brick setting, ...	Common.

Results of Tests. (Average of two.)

	Test No. 65.	Test No. 66.	Test No. 67.
Kind of coal, :	Anthracite, Stove.	Anthracite, Chestnut No. 2.	2 pts. Pea and Dust, 1 part Clearfield.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.	Ordinary.
Duration, ... hrs.	10.7	11	10.7
Coal consumed dry (including wood equivalent), ... lbs.	2,661	2,700	2,789
Percentage of ash, ... %	14.7	12.8	14
Water evaporated, ... lbs.	21,213	21,350	22,030
Coal per hour, ... lbs.	247.7	245.5	259.4
Coal per hour per sq. ft. of grate, . lbs.	9.3	9.6	9.7
Water per hour, ... lbs.	1,974.4	1,941	2,049.3
Water per hour per square foot of heating surface, ... lbs.	2.2	2.2	2.3
Horse-power developed, . H. P.	66.9	65.8	69.3
Boiler pressure, ... lbs.	65.8	64.8	67.9
Temperature of feed-water, . . deg.	67	66.5	71
Temperature of escaping gases, . deg.	314	312	326
Number of firings, ...	20	37	39
Number of times slice bar was used, .	1	1	12
Position of damper, ...	¼ open.	¼ open.	½ open.
Water per pound of coal, . . lbs.	7.97	7.90	7.90
Water per pound of coal from and at 212 degrees, ... lbs.	9.43	9.34	9.31
Water per pound of combustible from and at 212 degrees, . . lbs.	11.06	10.72	10.85

NOTE. — The mixed fuel when fired contained 4½ per cent. of moisture.

The tests on boiler No. 27 had for an object the determination of the relative economy of different classes of fuel. A comparison of the results of the three tests shows that the chestnut No. 2 coal, and the mixed fuel as well, secured 1 per cent. less evaporation per pound of coal than the stove coal. The prices of the coals to which these figures applied, and the corresponding cost of fuel required to evaporate a given amount of water, say 30,000 pounds from and at 212 degrees, are given in the following table: —

	Stove.	Chestnut No. 2.	Mixture.
Cost per ton of 2,240 pounds, ...	$5.40	$4.50	$3.70
Cost of fuel for 30,000 pounds of steam, . .	7.63	6.42	5.33

A comparison of these figures shows that the cost of making a given amount of steam with chestnut No. 2 coal was 16 per cent. less than with stove coal, and the cost with the mixture was 30 per cent. less.

The low temperature of the escaping gases is noticeable in these tests. This is an indication of economical work which the favorable character of the evaporative results plainly bears out.

Boiler No. 28.

Kind of boilers, ...	Horizontal return tubular.
Number used, ...	Three.
Horse-power (collective, basis 12 sq. ft.),	One hundred and twenty-nine.
Age, ...	Several years.

Dimensions.

Diameter of shell, ...	48	in.
Length between heads and length of tubes, ...	12	ft.
Number of tubes (collective) 3 inches outside diameter, .	147	
Area of water-heating surface, ...	1,548	sq. ft.
Area of steam-heating surface, ...	185	sq. ft.
Area of grate surface, ...	58.5	sq. ft.
Area through tubes, ...	6.1	sq. ft.
Height of chimney, ...	140	ft.
Width of air spaces and metal bars in grates, .	Air 7-16 in., metal 3-8 in.	
Distance of grate to shell, ...	16	in.
Distance of flat bridge to shell, ...	5	in.
Character of space behind bridge, ...	Open.	
Ratio of water-heating surface to grate surface, . .	26.5 to 1	
Ratio of grate to tube area, ...	9.6 to 1	
Kind of brick setting, ...	Common.	

Results of Tests.

	Test No. 68.	Test No. 69.	Test No. 70.
Kind of coal,	Anthracite White Ash, Broken.	Anthracite, Pea.	44 parts Pea and Dust, 37 parts Nova Scotia Culm.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.	Ordinary.
Duration, ... hrs.	10.2	10.5	10.5
Coal consumed dry (including wood equivalent), ... lbs.	7,848	6,584	7,595
Percentage of ash, ... %	10.1	20.9	17.9
Water evaporated, ... lbs.	56,715	45,071	47,452
Coal per hour, ... lbs.	756.6	627	723.3
Coal per hour per sq. ft. of grate, . lbs.	12.9	11.7	13.6
Water per hour, ... lbs.	5,532.6	4,292.4	4,519.2
Water per hour per square foot of water-heating surface, . . lbs.	3.6	2.8	2.9
Horse-power developed, . . H. P.	192.3	149.2	157.1
Boiler pressure, ... lbs.	73.7	74.2	73
Temperature of feed-water, . . deg.	39	39	39
Temperature of escaping gases, . deg.	455	448	460
Draught suction, ... in.	0.11	0.12	0.28
Number of firings, ...	23	27	34
Number of firings using slice-bar or hoe, ...	6	5	24
Water per pound of coal, . . lbs.	7.23	6.84	6.24
Water per pound of coal from and at 212 degrees, ... lbs.	8.77	8.29	7.57
Water per pound of combustible from and at 212 degrees, . . lbs.	9.75	10.63	9.34

NOTE. — The pea coal when fired contained 5 per cent. of moisture and the mixture 10 per cent.

The tests on boiler No. 28 exhibit the performance of old boilers of small diameter and short length, set with little vertical distance between the grate and shell, and probably coated to some extent with scale. The ratio of heating surface to grate is small, and there is a correspondingly high temperature of the escaping gases. Under these circumstances a high degree of economy cannot be expected, and, as the results show, it was not realized.

The tests also furnish a comparison, under the circumstances, between the economy of three kinds of coal. The

evaporation per pound of coal is 5.5 per cent. less with pea coal than with broken coal, and 13.7 per cent. less with the mixed fuel. Based on the cost of the fuels required to produce a given quantity of steam, say 30,000 pounds from and at 212 degrees, according to the existing prices which are given below,

	Broken.	Pea.	Mixture.
Cost per ton of 2,240 pounds, ...	$6.10	$4.75	$3.85
Cost for 30,000 pounds of steam, . . .	9.32	7.64	6.81

the economy of pea coal over broken coal is 18 per cent., and that of the mixture 26.9 per cent.

The quantity of power developed on these tests is high, considering the strength of draught. In all cases it is a considerable amount above the rated capacity, with a draught much below the full power of the chimney.

Boiler No. 29.

Kind of boiler, ...	Vertical tubular (rolling-pin).
Number used, ...	One.
Horse-power (basis 10 square feet), .	One hundred and forty.
Kind of coal, ...	Two parts Anthracite Screenings, one part Cumberland.
Age, ...	Ten years.

Dimensions.

Diameter main shell, ...	90	in.
Diameter drum and water leg, ...	29	in.
Length of main shell and tubes, ...	9	ft. 9 in.
Number of tubes 2 inches outside diameter, ...	248	
Area of water-heating surface, ...	936	sq. ft.
Area of steam-heating surface, ...	517	sq. ft.
Area of total heating surface, ...	1,453	sq. ft.
Area of grate surface, ...	45.6	sq. ft.
Area through tubes, ...	4.1	sq. ft.
Area through flue, ...	2.8	sq. ft.

Height of chimney,	125 ft.
Width of air spaces and metal bars in grates,	1-2 in.
Ratio of water-heating surface to grate surface,	21.1 to 1
Ratio of steam-heating surface to grate surface,	10.7 to 1
Ratio of total heating surface to grate surface,	31.8 to 1
Ratio of grate to tube area,	11 to 1
Ratio of grate to flue area,	16.1 to 1
Kind of brick setting,	Passages in walls supplying air to furnace above the fuel.

Results of Tests.

	Test No. 71.	Test No. 72.
Conditions as to admission of air over fuel,	Air admitted.	Air excluded.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.
Duration, ... hrs.	11	11.7
Coal consumed dry (including wood equivalent), ... lbs.	5,399	6,211
Percentage of ash, ... %	18.8	16.7
Water evaporated, ... lbs.	33,210	40,001
Coal per hour, ... lbs.	483.2	528.6
Coal per hour per square foot of grate, lbs.	10.7	11.6
Water per hour, ... lbs.	3,019.1	3,404.3
Water per hour per square foot water-heating surface, ... lbs.	3.2	3.6
Horse-power developed, . . H. P.	104.6	118.1
Boiler pressure, ... lbs.	72.5	72.5
Temperature of feed-water, . . deg.	42	42
Temperature of escaping gases, . . deg.	443	434
Number of degrees superheating, . deg.	93	93
Draught suction, ... in.	0.26	0.32
Water per pound of coal, ... lbs.	6.15	6.44
Water per pound of coal from and at 212 degrees, ... lbs.	7.46	7.79
Water per pound of combustible from and at 212 degrees, ... lbs.	9.06	9.27

NOTE. — The coal when fired contained 10 per cent. of moisture.

Boiler No. 29 has no peculiarities for the rolling-pin type of vertical boiler, excepting the provision for supplying air to the products of combustion at the surface of the fire. The special interest attaching to the tests is the effect which the admission or exclusion of air had upon the economy and capacity of the boiler. The damper was kept in a constant position for both

tests, and there was a steady draught of 0.7 inch on the chimney side of the damper. The effective draught in the boiler flue was 0.26 inch when the air was admitted and 0.32 inch when it was excluded, and, as a consequence, the power developed was increased by excluding the air from 209.2 horse-power to 236.2 horse-power, an increase of 13 per cent. In the matter of economy, the exclusion of air was followed by an increase of 4.3 per cent. in the evaporation per pound of coal, and of 2.3 per cent. per pound of combustible.

The economic results as a whole must take into account the character of the steam, which was in a somewhat highly superheated state. The superheating of 93 degrees adds about 4 per cent. more heat to the steam and increases its value for purposes of motive power some 8 per cent. If the last quantity is allowed for, it brings the evaporation per pound of combustible from and at 212 degrees in test No. 72 to 10.01 pounds. This result is about one pound below that obtained from some of the horizontal boilers that have been tested, and the difference is largely attributed to the high temperature of the escaping gases, coupled with the leakage of air through the brick-work of the setting — the high temperature being evidently due to the small proportion of water-heating surface to grate surface.

BOILER No. 30.

Kind of boiler,	Vertical tubular (rolling-pin).
Number used,	One.
Horse-power (basis 10 square feet),	One hundred and forty.
Age,	Ten years.

Dimensions.

Diameter of main shell,	90 in.
Diameter of drum and water leg,	29 in.
Length of main shell and tubes,	9 ft. 9 in.
Number of tubes 2 inches outside diameter,	248
Area of water-heating surface,	940 sq. ft.
Area of steam-heating surface,	513 sq. ft.
Area of grate surface,	45.7 sq. ft.
Area through tubes,	4.1 sq. ft.

Area through flue,	2.8 sq. ft.
Width of air spaces and metal bars in grates,	1-2 in.
Distance of grate to tube sheet,	2 ft. 7 in.
Ratio of water-heating surface to grate surface,	20.6 to 1
Ratio of steam-heating surface to grate surface,	11.2 to 1
Ratio of grate to tube area,	11 to 1
Kind of brick setting,	Common.

Results of Tests.

	Test No. 73.	Test No. 74.	Test No. 75.
Kind of coal,	George's Creek Cumberland.	Anthracite Lehigh, Broken.	2 pts. Screenings, 1 part Cumberland.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.	Ordinary.
Duration, hrs.	11.7	12.5	11.7
Coal consumed dry (including wood equivalent), lbs.	4,070.4	5,592	6,211
Percentage of ash, %	8.2	15.1	16.7
Water evaporated, lbs.	31,888	37,504	40,001
Coal per hour, lbs.	346.5	447.4	528.6
Coal per hour per sq. ft. of grate, lbs.	7.3	9.8	11.6
Water per hour, lbs.	2,713.8	3,000.3	3,404.3
Water per hour per square foot of water-heating surface, lbs.	2.9	3.2	3.6
Horse-power developed, H. P.	94	103.8	118.1
Boiler pressure, lbs.	72.7	72.2	72.5
Temperature of feed-water, deg.	44	44	42
Temperature of escaping gases, deg.	413	449	434
Number of degrees of superheating, deg.	73	89	93
Draught suction, in.	0.07	0.05	0.32
Number of firings,	23	15	31
Number of times slice-bar or stoker used,	22	3	22
Water per pound of coal, lbs.	7.83	6.71	6.44
Water per pound of coal from and at 212 degrees, lbs.	9.46	8.11	7.79
Water per pound of combustible from and at 212 degrees, lbs.	10.27	9.54	9.27

NOTE. — The Cumberland coal when fired contained 4 per cent. of moisture and the mixture 9 per cent.

The three tests on boiler No. 30 show the performance of different fuels on a vertical tubular boiler. The relation between the results is much the same as that obtained in the horizontal type of boiler. The evaporation per pound of Cumberland coal is 16.6 per cent. greater, and that per pound of

mixed fuel is 4 per cent. less, than the performance of the anthracite coal. On the basis of cost of fuel, according to the quotations given below,

	Cumberland.	Anthracite, Broken.	Mixture.
Cost per ton of 2,200 pounds, . . .	$5.50	$5.50	$3.50
Cost for 30,000 pounds of steam, . .	7.81	9.24	6.03

the cost of Cumberland coal required to evaporate 30,000 pounds of water from and at 212 degrees is 15.5 per cent. less, and that of the mixture 34.7 per cent. less, than the cost of anthracite broken coal.

The relatively small amount of draught required in burning the standard grades of coal is noticeable, although the boiler developed somewhat less than the rated power, and the rate of combustion was low. The draught on test No. 74 is less than one-sixth of the full capacity of a good chimney. The Cumberland coal required a slightly stronger draught than the anthracite coal, and the mixed fuel required six times as much.

The small proportion of water-heating surface and the consequent rapid evaporation per square foot of surface, and the high temperature of escaping gases, as also the high degree to which the steam is superheated, are characteristic of this type of boiler. The generally inferior nature of the economic results is what might be expected in view of these conditions.

The relative labor of firing the various coals is seen in the number of times of firing and using the slicing-bar. The mixed fuel is at the greatest disadvantage in this respect.

BOILER No. 31.

Kind of boilers, ...	Vertical tubular.
Number used, ...	Five.
Horse-power (collective, basis 10 sq. ft.),	Four hundred and seventy-five.
Kind of coal, ...	Anthracite Lehigh, Broken.
Age, ...	One year.

Dimensions.

Diameter of shell,	64	in.
Length between heads and length of tubes,	14	ft.
Number of tubes (collective) 3 inches outside diameter,	420	
Area of water-heating surface,	3,300	sq. ft.
Area of steam-heating surface,	1,455	sq. ft.
Area of total heating surface,	4,755	sq. ft.
Area of grate surface,	157.5	sq. ft.
Area through tubes,	17.2	sq. ft.
Area through flue,	27.1	sq. ft.
Distance of grate to tube sheet,	3 ft. 7 in.	
Ratio of water-heating surface to grate surface,	20.9	to 1
Ratio of steam-heating surface to grate surface,	9.2	to 1
Ratio of grate to tube area,	9.1	to 1
Kind of brick setting,	Common.	

Results of Tests.

	Test No. 76.	Test No. 77.	Test No. 78.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.	Ordinary.
Duration, ... hrs.	11.5	11.5	12
Coal consumed (including wood equivalent), ... lbs.	25,904	22,925	17,635
Percentage of ash, ... %	10.3	13.2	13.2
Water evaporated, ... lbs.	158,705	148,686	112,995
Coal per hour, ... lbs.	2,252	1,990	1,469.5
Coal per hour per sq. ft. of grate, . lbs.	14.3	12.7	9.3
Water per hour, ... lbs.	13,800.4	12,929.2	9,416.2
Water per hour per square foot water-heating surface, . . lbs.	4.2	3.9	2.8
Horse-power developed, . . H. P.	555.6	522.5	327
Boiler pressure, ... lbs.	72.1	72	72.1
Temperature of feed-water, . . deg.	126	121	39
Temperature of escaping gases, . deg.	545	509	417
Number of degrees of superheating, deg.	80	73	71
Draught suction, ... in.	0.16	0.16	0.09
Water per pound of coal, . . lbs.	6.13	6.49	6.41
Water per pound of coal from and at 212 degrees, ... lbs.	6.87	7.33	7.77
Water per pound of combustible from and at 212 degrees, . . lbs.	7.63	8.43	8.96

Boiler No. 31 has a brick furnace and the walls extend about half way up on the sides of the boiler. Above this point the shell is protected by non-conducting covering.

The three tests on boiler No. 31 afford an example of the performance of a vertical boiler, which is deficient in heating surface, and the effect of different rates of combustion. The best performance is inferior in point of economy to that obtained from horizontal boilers containing no more total heating surface than that found here, even with an extreme allowance for the superior efficiency of the superheated steam. The cause of the difference is explained in part by the high temperature of the escaping gases. The vertical boiler with brick setting provides a large amount of area about the furnace for radiation and leakage of air into the furnace, both of which are sources of loss.

The unfavorable effect of a high rate of combustion is here shown. An increase in the rate from 9.3 pounds per square foot of grate to 14.3 pounds is accompanied by an increase in the flue temperature from 417 degrees to 545 degrees, and a decrease in the evaporation per pound of combustible from 8.96 pounds to 7.63 pounds or 15 per cent.

The low draught required for a vertical boiler is here noticeable, 0.16 inch being sufficient to burn 14.3 pounds of anthracite coal per square foot of grate per hour — the draught suction being less than half the full capacity of a moderately high chimney.

It is to be noted that these boilers have 3-inch tubes, and the proportion between the collective tube area and grate surface is larger than in some forms of vertical boilers. It is probable that the excess of tube area had an unfavorable effect upon the economy.

BOILER No. 32.

Kind of boiler,	Water-tube.
Number used,	One.
Horse-power (basis 12 square feet),	Seventy.
Kind of coal,	Anthracite Lehigh, Chestnut.
Age,	Six months.

Dimensions.

Number of tubes 4 inches outside diameter,	84	
Length of tubes,	16	ft.

Area of heating surface,	840	sq. ft.
Area of grate surface,	22.5	sq. ft.
Width of air spaces and metal bars in grates,	1-4	in.
Area through flue and chimney,	4	sq. ft.
Height of chimney,	57	ft.
Ratio of heating surface to grate surface,	37.3	to 1
Ratio of grate to flue area,	5.6	to 1
Kind of brick setting,	Passages in walls supplying air to sides of furnace and bridge.	

Results of Test.

	Test No. 79.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	10.7	hrs.
Coal consumed (including wood equivalent),	2,252	lbs.
Percentage of ash,	14	%
Water evaporated,	19,178	lbs.
Coal per hour,	209.5	lbs.
Coal per hour per square foot of grate,	9.3	lbs.
Water per hour,	1,784	lbs.
Water per hour per square foot of heating surface,	2.1	lbs.
Horse-power developed,	54.8	H. P.
Boiler pressure,	89	lbs.
Temperature of feed-water,	180	deg.
Temperature of escaping gases,	337	deg.
Draught suction,	0.09	in.
Water per pound of coal,	8.52	lbs
Water per pound of coal from and at 212 degrees,	8.79	lbs.
Water per pound of combustible from and at 212 degrees,	10.61	lbs.

The test on boiler No. 32 is of general interest in showing the performance of a water-tube boiler working under somewhat unfavorable conditions. The coal is of an inferior grade and the boiler developed much less than its rated power.

The admission of air above the fire is no doubt a disadvantage in this case. The results of this test do not differ materially from the general results of the tests with chestnut coal made on boilers Nos. 24, 25 and 26.

BOILER NO. 33.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Fifty-three.
Age,	Six months.

Dimensions.

Diameter of shell,	48	in.
Length between heads and length of tubes,	15	ft.
Number of tubes 3 inches outside diameter,	49	
Area of heating surface,	640	sq. ft.
Area of grate surface (total of 2 furnaces),	11.7	sq. ft.
Area through tubes,	2	sq. ft.
Height of chimney,	50	ft.
Width of air spaces and metal bars in grates,	5-8	in.
Distance of grate to shell,	18	in.
Distance of bridges to shell,	7	in.
Ratio of heating surface to grate surface,	54.4	to 1
Ratio of grate to tube area,	5.9	to 1
Kind of brick setting,	Double furnace, for alternate firing	

Results of Tests.

		Test No. 80.	Test No. 81.
Kind of coal,		Bituminous Cumberland.	Anthracite Lehigh, Broken.
Manner of start and stop and kind of run,		Ordinary.	Ordinary.
Duration,	hrs.	10.5	11
Coal consumed dry (including wood equivalent),	lbs.	2,368	1,587
Percentage of ash,	%	8.5	13.5
Water evaporated,	lbs.	19,734	11,496
Coal per hour,	lbs.	225.5	144.3
Coal per hour per sq. ft. of grate,	lbs.	19.3	12.5
Water per hour,	lbs.	1,879.4	1,045.1
Water per hour per square foot heating surface,	lbs.	2.9	1.6
Horse-power developed	H. P.	65.3	36.3
Boiler pressure,	lbs.	50.1	50.9
Temperature of feed-water,	deg.	41	41
Temperature of escaping gases,	deg.	472	354
Draught suction,	in.	0.25	0.12
Water per pound of coal,	lbs.	8.33	7.24
Water per pound of coal from and at 212 degrees,	lbs.	10.00	8.69
Water per pound of combustible from and at 212 degrees,	lbs.	10.93	10.05

Boiler No. 33 has a special arrangement of setting. A furnace is placed under each end of the boiler, located in the

same manner with reference to the boiler as the furnace in the common horizontal boiler. A damper is provided in each front connection for the control of the flue gases, and another above each furnace at the entrance to the chamber in front of the tubes, to control the passage of the products of combustion into the boiler. The method of operation consists in firing the furnaces alternately. The products of combustion from either furnace are made to pass over the burning coal in the other furnace, whenever either one is supplied with fresh coal. Just previous to each firing the dampers are changed so that the desired result may be secured. The object of this form of setting is to secure more thorough combustion and increased economy. The fire in the secondary furnace serves to heat and ignite the unburned gases formed in the first.

Taking the results of the test with anthracite coal, it appears that the temperature of the escaping gases was low, with a reasonably high rate of combustion, and it may be reasonably assumed that the boiler was working with as good economy as could be obtained. The result was 10.05 pounds of water from and at 212 degrees per pound of combustible, which, for this kind of coal, must be regarded as an inferior performance. Taking the test with bituminous coal, the result is more favorable, if account is taken of the high temperature of the waste gases; but, as it stands, it is inferior to the figures often obtained from the horizontal tubular boiler with the ordinary setting.

The quantity of smoke issuing from the chimney when Cumberland coal was used, was materially less than occurs with the ordinary boiler setting, and this is an indication that the system exerts a favorable effect as a smoke preventer.

BOILER NO. 34.

Kind of boilers, ...	Horizontal return tubular
Number used, ...	Four.
Horse-power (collective, basis 12 sq. ft.),	Two hundred and seventy-five.
Kind of coal, ...	Bituminous Cumberland.

Dimensions.

Diameter of shell,	60	in.
Length between heads and length of tubes,	12	ft.
Number of tubes (collective) 3 inches outside diameter,	336	
Area of heating surface,	3,534	sq. ft.
Area of grate surface,	120	sq. ft.
Area through tubes,	13.8	sq. ft.
Area through flue,	15.9	sq. ft.
Height of chimney,	123	ft.
Width of air spaces and metal bars in grates,	Air 3-8 in., metal 7-16	in.
Distance of grate to shell,	24	in.
Distance of flat bridge to shell,	9	in.
Character of space behind bridge,	Open.	
Ratio of heating surface to grate surface,	29.4	to 1
Ratio of grate to tube area,	8.7	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No. 82.	
Manner of start and stop,	Thin fire.	
Kind of run,	Continuous.	
Duration,	10.2	hrs.
Coal consumed dry,	13,293	lbs.
Percentage of ash,	8.7	%
Water evaporated,	113,115	lbs.
Coal per hour,	1,307.6	lbs.
Coal per hour per square foot of grate,	10.9	lbs.
Water per hour,	11,125.6	lbs.
Water per hour per square foot of heating surface,	3.1	lbs.
Horse-power developed,	380	H. P.
Boiler pressure,	91	lbs.
Temperature of feed-water,	117	deg.
Temperature of escaping gases,	530	deg.
Draught suction,	0.31	in.
Water per pound of coal,	8.50	lbs.
Water per pound of coal from and at 212 degrees,	9.67	lbs.
Water per pound of combustible from and at 212 degrees,	10.60	lbs.

NOTE. — The coal when fired contained 3 per cent. of moisture.

The test on boiler No. 34 gives the performance of Cumberland coal upon a horizontal return tubular boiler having short tubes and a comparatively small amount of heating surface. The ratio of heating surface to grate surface is 29.4 to 1. The

rate of combustion is not high, being only 10.9 pounds of coal per square foot of grate per hour, but the temperature of the waste gases is excessive, due, no doubt in part, to the deficiency of heating surface. The high temperature of the gases and the low evaporative result go hand in hand, and one may be reasonably attributed to the other. Compared with other tests which have been given, the waste heat appears somewhat higher than would be expected in view of the rate of combustion and the area of heating surface, and it is possible that some of this was due to the presence of scale in the boiler.

Boiler No. 35.

Kind of boilers,	Water-tube.
Number used,	Two.
Horse-power (collective, basis 12 sq. ft.),	Two hundred and thirty-four.
Kind of coal,	Anthracite Shamokin, Pea.
Age,	Three years.

Dimensions.

Number of tubes (collective) 4 inches outside diameter,	128	
Length of tubes,	18	ft.
Area of heating surface,	2,807	sq. ft.
Area of grate surface,	70.8	sq. ft.
Area through flue,	9.8	sq. ft.
Width of air spaces and metal bars in grates,	Air 5-16 in., metal 7-16 in.	
Ratio of heating surface to grate surface,	40	to 1
Ratio of grate surface to flue area,	7.2	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No. 83.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	11	hrs.
Coal consumed dry (including wood equivalent),	10,884	lbs.
Percentage of ash,	16.6	%
Water evaporated,	92,336	lbs.
Coal per hour,	989.5	lbs.
Coal per hour per square foot of grate,	14	lbs.
Water per hour,	8,394.3	lbs.
Water per hour per square foot of heating surface,	3	lbs.
Horse-power developed,	255.8	H. P.
Boiler pressure,	101	lbs.

	Test No. 83.	
Temperature of feed-water,	151	deg.
Temperature of escaping gases,	371	deg
Draught suction,	0.36	in.
Percentage of moisture in steam,	0.6	%
Water per pound of coal,	8.48	lbs.
Water per pound of coal from and at 212 degrees,	9.39	lbs.
Water per pound of combustible from and at 212 degrees,	11.26	lbs.

NOTE. — The coal when fired contained 5 per cent. of moisture.

Boiler No. 35 differs from the ordinary water-tube boiler in being provided with a small flue heater. The area of heating surface which it contained was 260 square feet, which is 9 per cent. of that in the boiler. The temperature of the escaping gases given was taken between the heater and the chimney. The heater added 18 degrees to the temperature of the water.

Test No. 83 exhibits the performance of a water-tube boiler under favorable circumstances. The horse-power developed is somewhat above the rated capacity, the rate of combustion is reasonably high, and the temperature of the escaping gases is quite low. These conditions are all favorable and the result is seen to be exceptional for the fine grade of anthracite coal which was used. The favorable result can be attributed in only a slight degree to the action of the flue heater.

BOILERS NOS. 36 AND 37.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power each (basis 12 sq. ft.),	Eighty.
Kind of coal each,	Three parts Pea and Dust, one part Cumberland.
Age,	No. 36 two years, No. 37 one year.

Dimensions for Each.

Diameter of shell,	60	in.
Length between heads and length of tubes,	15	ft.
Number of tubes 3½ inches outside diameter,	64	
Area of heating surface,	959	sq. ft.

Area of grate surface,	25.8 sq. ft.
Area through tubes,	3.7 sq. ft.
Area through flue,	3 sq. ft.
Height of chimney,	75 ft.
Width of air spaces and metal bars in grates,	3-8 in.
Distance of grate to shell,	26 in.
Distance of flat bridge to shell,	9 in.
Character of space behind bridge,	Filled, inclined covering.
Ratio of heating surface to grate surface,	37.1 to 1
Ratio of grate surface to tube area,	7 to 1
Kind of brick setting,	No. 36, passages in walls admitting air to sides of furnace and bridge. No. 37, common.

Results of Tests. (Average of 2 runs.)

		Boiler No. 36. Test No. 84.	Boiler No. 37. Test No. 85.
Manner of start and stop and kind of run,		Ordinary.	Ordinary.
Duration,	hrs.	10.5	10.5
Coal consumed dry (including wood equivalent),	lbs.	2,842	3,110
Percentage of ash,	%	14.1	14.5
Water evaporated,	lbs.	20,649	23,581
Coal per hour,	lbs.	270.8	296.4
Coal per hour per square foot of grate,	lbs.	10.46	11.46
Water per hour,	lbs.	1,967.7	2,247.3
Water per hour per square foot of heating surface,	lbs.	2.1	2.3
Horse-power developed,	H. P.	68.4	78.7
Boiler pressure,	lbs.	56.3	63
Temperature of feed-water,	deg.	39.5	39.5
Temperature of escaping gases,	deg.	467	474
Draught suction,	in.	0.37	0.39
Water per pound of coal,	lbs.	7.24	7.58
Water per pound of coal from and at 212 degrees,	lbs.	8.76	9.17
Water per pound of combustible from and at 212 degrees,	lbs.	10.23	10.74

NOTE. — The coal when fired contained 3½ per cent of moisture.

The tests on boilers Nos. 36 and 37 were made to determine the effect produced by the admission of air over the fire, one boiler being arranged to admit air which had passed through the side walls, and the other having no provision of this kind.

In other respects, the two boilers were identical both as to size and arrangement, but one had been in use a somewhat longer period of time than the other. The tests were conducted simultaneously with fuel which had been thoroughly mixed so as to obtain the same quality for both cases.

The results show an appreciable loss in the case of boiler No. 36, the evaporation being nearly 5 per cent. below that of No. 37, and this inferior performance can only be attributed to the unfavorable effect produced by the admission of air above the fuel

It appears that in both cases the temperature of the waste gases was higher than boilers show which work with the best economy.

Boiler No. 37 was subsequently tried with anthracite broken coal, containing 13.3 per cent. of ash, and burning 10.5 pounds of coal per square foot of grate per hour, with a draught of 0.29 of an inch, and gave an evaporation of 11.04 pounds of water per pound of combustible from and at 212 degrees. This is a favorable result considering the temperature of the gases, which was 463 degrees. The horse-power developed was 150.

BOILER No. 38.

Kind of boiler,	Water-tube.
Number used,	One.
Horse-power (basis 12 square feet),	One hundred.
Kind of coal,	Anthracite Lehigh, Broken.
Age,	Six months.

Dimensions.

Number of tubes,	54
Length of tubes,	18 ft.
Area of heating surface,	1,196 sq. ft.
Area of grate surface,	28.7 sq. ft.
Area through flue,	9.8 sq. ft.
Width of air spaces and metal bars in grates,	Air 3-8 in., metal 1-4 in.
Ratio of heating surface to grate surface,	40.3 to 1
Ratio of grate surface to flue area,	6.1 to 1
Kind of brick setting,	Common.

Results of Test.

	Test No. 38.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	10.5	hrs.
Coal consumed,	5,553	lbs.
Percentage of ash,	9.2	%
Water evaporated,	45,803	lbs.
Coal per hour,	528.8	lbs.
Coal per hour per square foot of grate,	17.8	lbs.
Water per hour,	4,362.2	lbs.
Water per hour per square foot of heating surface,	3.6	lbs.
Horse-power developed,	133.1	H. P.
Boiler pressure,	73	lbs.
Temperature of feed-water,	183	deg.
Temperature of escaping gases,	540	deg.
Water per pound of coal,	8.24	lbs.
Water per pound of coal from and at 212 degrees,	8.77	lbs.
Water per pound of combustible from and at 212 degrees,	9.68	lbs.

The test on boiler No. 38 shows the performance of a water-tube boiler having favorable proportions and using a standard grade of fuel, but working under unfavorable conditions for economy. The rate of combustion was 17.8 pounds per square foot of grate per hour, which, for this class of fuel, is ordinarily too high for economical work. The high temperature of the waste gases, which is 540 degrees, reveals the locality of the loss, and indicates the reason for the low evaporative result. The horse-power developed is one-third above the rated power.

BOILER No. 39.

Kind of boilers,	Vertical tubular (nest).
Number used,	Two.
Horse-power (collective, basis 10 sq. ft.),	Three hundred and eighty.
Kind of coal,	Anthracite, Chestnut No. 2.
Age,	Ten years.

Dimensions.

Diameter of central shell,	36	in.
Length of central shell,	21	ft.
Diameter of outer shells (6 in number), each,	30	in.
Length of outer shells and length of tubes,	10	ft.

Number of tubes (collective) 2 inches outside diameter,	516	
Area of water-heating surface,	2,224	sq. ft.
Area of steam-heating surface,	1,566	sq. ft.
Area of total heating surface,	3,790	sq. ft.
Area of grate surface,	143	sq. ft.
Area through tubes,	8.6	sq. ft.
Area through flue,	10	sq. ft.
Ratio of water-heating surface to grate surface,	15.5	to 1
Ratio of steam-heating surface to grate surface,	11	to 1
Ratio of grate surface to tube area,	16.6	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No. 87.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	11	hrs.
Coal consumed,	11,862	lbs.
Percentage of ash,	12.9	
Water evaporated,	82,584	lbs.
Coal per hour,	1,078.4	lbs.
Coal per hour per square foot of grate,	7.5	lbs.
Water per hour,	7,507.6	lbs.
Water per hour per square foot of water-heating surface,	3.4	lbs.
Horse-power developed,	242.8	H. P.
Boiler pressure,	83	lbs.
Temperature of feed-water,	120	deg.
Temperature of escaping gases,	468	deg.
Number of degrees of superheating,	31	deg.
Draught suction,	0.08	in.
Water per pound of coal,	6.96	lbs.
Water per pound of coal from and at 212 degrees,	7.86	lbs.
Water per pound of combustible from and at 212 degrees,	8.91	lbs.

Boiler No. 39 is a vertical tubular boiler consisting of six vertical shells filled with tubes, surrounding and communicating with a central shell. The whole is enclosed in a circular wall which forms the setting. The flue space is separated from the furnace space by iron plates fitting around the shells. This type of boiler does not differ in principle from the ordinary vertical boiler, but it differs somewhat in the proportions. It has a low proportion of water-heating surface to grate surface, namely, 15.5 to 1, and a correspondingly

high proportion of steam-heating surface. The tube area is small.

The test was made using one of the inferior grades of anthracite coal. The rate of combustion is low, and there is consequently a small amount of power developed. The power is nearly 40 per cent. below the nominal power. In spite of this low rate, the temperature of the escaping gases is high, being 468 degrees, and the economic result is inferior.

In this type of boiler, as in other vertical boilers set in brick-work, there is a large exterior surface exposed to the air. This surface not only causes radiation, but, owing to the unstable condition of brick-work which has had a long period of service, it provides many avenues for the entrance of air both to the furnace and to the flue space. The effect of unnecessary admission of air is to reduce the efficiency of the fuel and to lower the temperature of the gases. The last named effect causes the apparent indication of waste heat to be much less than the real quantity.

Boiler No. 40.

Kind of boilers,	Plain cylinder.
Number used,	Four.
Horse-power (collective, basis 6 sq. ft.),	Two hundred and twenty.
Kind of coal,	Anthracite, Chestnut No. 2.
Age,	Ten years.

Dimensions.

Diameter of shells (3 in each),	30	in.
Length of shells,	30	ft.
Area of heating surface,	1,320	sq. ft.
Area of grate surface,	175	sq. ft.
Area through flue,	10.5	sq. ft.
Height of chimney,	120	ft.
Width of air spaces and metal bars in grates,	3-8	in.
Distance of grate to shell,	16	in.
Ratio of heating surface to grate surface,	7.5	to 1
Ratio of grate surface to flue area,	16.7	to 1
Kind of brick setting,	Common.	

Results of Tests.

	Test No. 88.	Test No. 89.
Manner of start and stop and kind of run,	Ordinary.	Ordinary.
Duration, ... hrs.	10.7	11.5
Coal consumed dry (including wood equivalent), ... lbs.	14,061	12,264
Percentage of ash, ... %	14	14.7
Water evaporated, ... lbs.	98,256	83,416
Coal per hour, ... lbs.	1,308	1,066.4
Coal per hour per square foot of grate, . lbs.	7.4	6.1
Water per hour, ... lbs.	9,140.1	7,253.6
Water per hour per square foot of heating surface, ... lbs.	6.9	5.5
Horse-power developed, . . . H. P.	272	240
Boiler pressure, ... lbs.	72.7	71.2
Temperature of feed-water, . . . deg.	207	93
Temperature of escaping gases, . . deg.	650	567
Water per pound of coal, ... lbs.	6.99	6.80
Water per pound of coal from and at 212 degrees, ... lbs.	7.27	7.89
Water per pound of combustible from and at 212 degrees, ... lbs.	8.44	9.22

NOTE. — The coal when fired contained 5 per cent. of moisture. On test No. 89 the ash-pit doors were partly closed.

Tests Nos. 88 and 89 give the performance of plain cylinder boilers working with two different rates of combustion, both of which are medium rates, when compared with the work of tubular boilers. These boilers have a proportion of only 7.5 square feet of heating surface to one of grate. This proportion is exceedingly low. The proportion in the horizontal tubular boiler is never below 25 to 1, and the proportion of water-heating surface in the vertical boiler is never below 15 to 1.

In view of the low results obtained on many of the boilers which have been given in this paper, the results on these boilers must be considered excellent. It is to be noted that the rate of evaporation per square foot of heating surface, which is 5.5 pounds, exceeds any figure ordinarily obtained from the most approved type of boiler, and the temperature of

the escaping gases is correspondingly high, yet the evaporation in the second test is 9.22 pounds of water from and at 212 degrees per pound of combustible, which is not more than 15 per cent. or 20 per cent. below the best result which can ordinarily be obtained with this class of fuel from the horizontal tubular form of boiler.

It is probable that the excessive temperature of the waste gases here is a true indication of the extent of the loss in economy.

It will be seen that the result of test No. 89 is quite as favorable as that of test No. 87, made on a vertical tubular boiler. One boiler is of the most primitive type, while the other was at one time considered the most approved example of modern steam generators.

Boiler No. 41.

Kind of boilers,	Cast-iron sectional.
Number used,	Eight.
Horse-power (collective, basis 12 sq. ft.),	Four hundred and sixty-six.
Kind of coal,	Anthracite, Chestnut No. 2.
Age,	Twelve years.

Dimensions.

Area of heating surface,	5,592	sq. ft.
Area of grate surface,	207.2	sq. ft.
Area through flue,	18	sq. ft.
Height of chimney,	110	ft.
Width of air spaces and metal bars in grates,	3-8	in.
Ratio of heating surface to grate surface,	27	to 1
Ratio of grate surface to flue area,	11.5	to 1
Kind of brick setting,	Common.	
Area of heating surface in flue heater,	1,280	sq.

Results of Tests.

		Test No. 90.	Test No. 91.
Conditions as to flue heater,		Heater in use.	Heater not in use.
Manner of start and stop and kind of run,		Ordinary.	Ordinary.
Duration,	hrs.	11	11
Coal consumed dry (including wood equivalent),	lbs.	20,400	22,789
Percentage of ash,	%	15.5	15.2
Water evaporated,	lbs.	153,650	157,166
Coal per hour,	lbs.	1,897.7	2,071.6
Coal per hour per square foot of grate,	lbs.	9.2	10
Water per hour,	lbs.	13,968	14,288
Water per hour per square foot of heating surface,	lbs.	2.5	2.6
Horse-power developed,	H. P.	454.4	486.9
Boiler pressure,	lbs.	82	82
Temperature of feed-water entering heater,	deg.	111	–
Temperature of feed-water entering boilers,	deg.	169	112
Temperature of escaping gases leaving boilers,	deg.	403	–
Temperature of escaping gases entering chimney,	deg.	299	434
Number of degrees flue heater added to water,	deg.	58	–
Number of degrees flue heater reduced gases,	deg.	104	–
Water per pound of coal,	lbs.	7.53	6.89
Water per pound of coal from and at 212 degrees,	lbs.	8.13	7.85
Water per pound of combustible from and at 212 degrees,	lbs.	9.62	9.68

NOTE. — The coal in test No. 90 when fired contained 5.5 per cent. of moisture; that in No. 91 contained 3.6 per cent.

Tests Nos. 90 and 91 exhibit the performance of cast-iron sectional boilers which had been subjected to a long period of service, and were covered to some extent with scale. This form of boiler is encased in brick-work which exposes a large extent of surface to the air. The exposure causes loss on the one hand by radiation, and on the other hand by leakage of air into the furnace and combustion chambers. As an indication of the extent to which leakage of air occurred, it may be said that a draught suction in the main flue amounting to 0.65 of an inch water pressure, was reduced to 0.34 of an inch in the

furnace of one of these boilers, with the fire-doors and ash-pit doors tightly closed and the damper wide open. Had there been no leakage, the full suction of the main flue would, under these circumstances, have been secured at the furnace.

Looking at the general result produced on test No. 91, it appears to be little better than that obtained on the plain cylinder boiler, test No. 89, in which the temperature of the waste gases was 567 degrees, or 133 degrees higher. The lower temperature evidently produced the greater proportionate loss on account of air leakage.

These tests are interesting in showing the effect produced by warming the feed-water by means of heat derived from the flue. The heater consists of vertical cast-iron pipes which are kept clean by means of scrapers, worked alternately up and down, and operated by power. A reduction of 104 degrees in the temperature of the gases, caused by passing through the heater, was accompanied by an addition of 58 degrees to the temperature of the feed-water, and an increase in the evaporation per pound of coal of 0.64 of a pound of water, which is 9.3 per cent.

An interesting question pertaining to this result is the actual economy secured by the use of the heater, when its cost is taken into account. The total cost of such a heater, including the cost of the setting and all expenses of transportation and erection, is some $2,500. The cost of fuel saved in a year on the basis of $3.50 per ton, figured upon the results here obtained, is about $1,000. Here is a yearly return of 40 per cent. upon the investment.

When the same heater was supplied with water at 200 degrees, and the flue gases entered at 380 degrees, the temperature of the water was raised 25 degrees.

BOILER No. 42.

Kind of boilers, ...	Horizontal return tubular.
Number used, ...	Two.
Horse-power (collective, basis 12 sq. ft.), .	Two hundred and twenty.
Kind of coal, ...	Anthracite Lehigh, Egg.
Age, ...	Twelve years.

Dimensions.

Diameter of shell,	60	in.
Length between heads and length of tubes,	17	ft.
Number of tubes (collective) 3 inches outside diameter,	192	
Area of heating surface,	2,680	sq. ft.
Area of grate surface,	39	sq. ft.
Area through flue,	9.8	sq. ft.
Width of air spaces and metal bars in grates,	Air 3-8 in., metal 7-16 in.	
Ratio of heating surface to grate surface,	68	to 1
Ratio of grate surface to tube opening,	4.9	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No. 92.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	10	hrs.
Coal consumed,	4,508	lbs.
Percentage of ash,	12.9	%
Water evaporated,	41,714	lbs.
Coal per hour,	450.8	lbs.
Coal per hour per square foot of grate,	11.5	lbs.
Water per hour,	4,171.4	lbs.
Water per hour per square foot of heating surface,	1.6	lbs.
Horse-power developed,	124.2	H. P.
Boiler pressure,	75	lbs.
Temperature of feed-water,	206	deg.
Temperature of escaping gases,	350	deg.
Water per pound of coal,	9.25	lbs.
Water per pound of coal from and at 212 degrees,	9.62	lbs.
Water per pound of combustible from and at 212 degrees,	11.03	lbs.

Boiler No. 42 is fitted with a much smaller grate than is generally used in a horizontal tubular boiler, and for this reason, the proportion of heating surface to grate surface, which is 68 to 1, is large, and that of grate to tube area is small. In these respects it is like the double-deck boilers which have been referred to elsewhere. The boiler is of somewhat greater length than that of the ordinary type. The temperature of the escaping gases is low, and the economic result obtained, viz., 11.03 pounds of water from and at 212 degrees per pound of combustible, is favorable. This test shows that a boiler which is called upon to produce a much less quantity of power than the rated power, can be made to work with good economy by simply reducing the grate surface.

Boiler No. 43.

Kind of boilers,	Horizontal return tubular.
Number used,	Three.
Horse-power (collective, basis 12 sq. ft.),	Four hundred and fifty.
Kind of coal,	Anthracite, Chestnut No. 2.
Age,	Three months.

Dimensions.

Diameter of shell,	72	in.
Length between heads and length of tubes,	16	ft.
Number of tubes (collective) 3 inches outside diameter,	420	
Area of heating surface,	5,412	sq. ft.
Area of grate surface,	90	sq. ft.
Area through tubes,	17.3	sq. ft.
Area through flue,	12.6	sq. ft.
Height of chimney,	85	ft.
Width of air spaces and metal bars in grates,	1-2	in.
Distance of grate to shell,	28	in.
Distance of flat bridge to shell,	10	in.
Character of space behind bridge,	Filled, covering level.	
Ratio of heating surface to grate surface,	60	to 1
Ratio of grate surface to tube area,	5.2	to 1
Ratio of grate surface to flue area,	7.1	to 1
Kind of brick setting,	Common, with air supplied at bridge.	

Results of Test.

	Test No. 93.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	10.7	hrs.
Coal consumed dry (including wood equivalent),	9,901	lbs.
Percentage of ash,	15.7	%
Coal per hour,	927.9	lbs.
Coal per hour per square foot of grate,	10.3	lbs.
Water per hour,	6,979.8	lbs.
Water per hour per square foot of heating surface,	1.3	lbs.
Horse-power developed,	241.5	H.P.
Boiler pressure,	80	lbs.
Temperature of feed-water,	44	deg.
Temperature of escaping gases,	316	deg.
Draught suction,	0.32	in.
Water per pound of coal,	7.52	lbs.
Water per pound of coal from and at 212 degrees,	9.10	lbs.
Water per pound of combustible from and at 212 degrees,	10.78	lbs.

Note. — The coal when fired contained 7 per cent. of moisture.

Boiler No. 43 exhibits the performance of a set of boilers having large shells and a large amount of heating surface in proportion to grate, using a low grade of anthracite coal containing, when fired, a considerable percentage of moisture. The air admitted at the bridge wall was through perforated cast-iron spheres exposed to the heat of the products of combustion. The quantity admitted was increased over that naturally drawn in, by means of a steam jet, which discharged into the passage leading to the bridge wall. The result of the test in point of economy is favorable. It would doubtless have been more favorable still if there had been less moisture in the coal. There is a low temperature of the escaping gases, an indication that the boiler absorbed nearly the whole of the heat. The quantity of power developed is but little over half the rated power of the boilers. The capacity is sacrificed for the sake of economy. It is questionable whether the sacrifice is a wise one, looked at from a commercial point of view, for it is probable that nearly if not quite as good economy from boilers of smaller diameter, containing a less number of tubes, and consequently a smaller amount of heating surface, might be obtained.

Boiler No. 44.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Fifty-three.
Kind of coal,	Anthracite, Broken.
Age,	Several years.

Dimensions.

Diameter of shell,	48	in.
Length between heads and length of tubes,	15	ft.
Number of tubes 3 inches outside diameter,	49	
Area of heating surface,	639	sq. ft
Area of grate surface,	24	sq. ft.
Area through tubes,	2	sq. ft.
Area through flue,	1.3	sq. ft.
Height of chimney,	55	ft.
Width of air spaces and metal bars in grates,	Air 5-8 in., metal 7-8 in.	
Distance of grate to shell,	17	in.

Distance of bridge wall to shell,	4 in.
Ratio of heating surface to grate surface,	26.6 to 1
Ratio of grate surface to tube area,	11.9 to 1
Kind of brick setting,	Common.

Results of Test.

	Test No. 94.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	11.2	hrs.
Coal consumed (including wood equivalent),	2,138	lbs.
Percentage of ash,	12	%
Water evaporated,	18,224	lbs.
Coal per hour,	190	lbs.
Coal per hour per square foot of grate,	7.9	lbs.
Water per hour,	1,619.9	lbs.
Water per hour per square foot of heating surface,	2.5	lbs.
Horse-power developed,	48.1	H. P.
Boiler pressure,	59	lbs.
Temperature of feed-water,	210.5	deg.
Temperature of escaping gases,	474	deg.
Draught suction,	0.30	in.
Water per pound of coal,	8.52	lbs.
Water per pound of coal from and at 212 degrees,	8.78	lbs.
Water per pound of combustible from and at 212 degrees,	9.87	lbs.

Test No. 94 gives a somewhat low evaporative result for anthracite broken coal. This is not surprising when the temperature of the escaping gases is taken into account, this temperature being 474 degrees. The cause of the high temperature is due probably to the small proportion which the heating surface bears to the grate surface. The proportion is 26.6 to 1.

The power developed is a considerable amount below the nominal power of the boiler. The small flue area is evidently the cause of the low rate of power, because the draught suction, which was 0.3 of an inch, is sufficient to secure much more power than was obtained.

BOILER No. 45.

Kind of boiler,	Vertical tubular (rolling-pin).
Number in use,	One.
Horse-power (basis 10 square feet),	One hundred and forty.
Kind of coal,	Anthracite Lackawanna, Egg.
Age,	Several years.

Dimensions.

Diameter of main shell,	90 in.
Diameter of drum and water leg,	31 in.
Length of main shell and tubes,	10 ft.
Number of tubes 2 inches outside diameter,	248
Area of water-heating surface,	897 sq. ft.
Area of steam-heating surface,	505 sq. ft.
Area of total heating surface,	1,402 sq. ft.
Area of grate surface,	45 sq. ft.
Area through tubes,	4.1 sq. ft.
Height of chimney,	90 ft.
Width of air spaces and metal bars in grates,	Air 5-8 in., metal 1-2 in.
Distance of grate to tube sheet,	2 ft. 8 in.
Ratio of water-heating surface to grate surface,	19.9 to 1
Ratio of steam-heating surface to grate surface,	11.3 to 1
Ratio of grate surface to tube area,	10.9 to 1
Kind of brick setting,	Common.

Results of Tests.

		Test No. 95.	Test No. 96.
Manner of start and stop and kind of run,		Ordinary.	Ordinary.
Duration,	hrs.	10.37	10.12
Coal consumed (including wood equivalent),	lbs.	5,602	6,472
Percentage of ash,	%	17	17.1
Water evaporated,	lbs.	35,482	39,646
Coal per hour,	lbs.	540.4	637.7
Coal per hour per square foot of grate,	lbs.	12	14.2
Water per hour,	lbs.	3,422.7	3,915.7
Water per hour per square foot of water-heating surface,	lbs.	3.8	4.4
Horse-power developed,	H. P.	119.8	137
Boiler pressure,	lbs.	79.5	77.8
Temperature of feed-water,	deg.	52	49
Temperature of escaping gases,	deg.	520	–
Draught suction,	in.	0.12	0.24
Number of degrees of superheating,	deg.	65	89
Water per pound of coal,	lbs.	6.33	6.13
Water per pound of coal from and at 212 degrees,	lbs.	7.61	7.37
Water per pound of combustible from and at 212 degrees,	lbs.	9.17	8.87

Tests Nos. 95 and 96 show the performance of a vertical tubular boiler under two rates of combustion, both of which

are comparatively high for a boiler having the proportions which obtain here, namely, 19.9 square feet of water-heating surface per square foot of grate surface. The temperature of the escaping gases is high, a condition which exists in small boilers of this class, and there is a correspondingly low economic result. The decreased economy due to the higher rate of combustion is marked, and the best result, which is 9.17 pounds, is much below that of the best class of boilers, even though an extreme allowance is made for the superior effect of the high degree of superheating.

It is interesting to note, in the comparison of these two tests with each other, that it required double the draught suction in order to increase the rate of combustion from 12 pounds to 14.2 pounds.

Boiler No. 46.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Eighty-eight.
Kind of coal,	Anthracite White Ash, Broken.
Age,	Six months.

Dimensions.

Diameter of shell,	60	in.
Length between heads and length of tubes,	16	ft.
Number of tubes 3 inches outside diameter,	80	
Area of heating surface,	1,047	sq. ft.
Area of grate surface,	23.7	sq. ft.
Area through tubes,	3.3	sq. ft.
Area through flue,	4	sq. ft.
Height of chimney,	62	ft.
Width of air spaces and metal bars in grates,	Air 5-8 in., metal 3-8 in.	
Distance of grate to shell,	18	in.
Distance of bridge to shell,	7	in.
Ratio of heating surface to grate surface,	44.2	to 1
Ratio of grate surface to tube area,	7.1	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No. 97.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	10.5	hrs.
Coal consumed (including wood equivalent),	2,492	lbs.
Percentage of ash,	15.7	%
Water evaporated,	20,219	lbs.
Coal per hour,	223.9	lbs.
Coal per hour per square foot of grate,	9.4	lbs.
Water per hour,	1,925.6	lbs.
Water per hour per square foot of heating surface,	1.8	lbs.
Horse-power developed,	107.6	H. P.
Boiler pressure,	60	lbs.
Temperature of feed-water,	202	deg.
Temperature of escaping gases,	369	deg.
Draught suction,	0.11	in.
Water per pound of coal,	8.60	lbs.
Water per pound of coal from and at 212 degrees,	8.94	lbs.
Water per pound of combustible from and at 212 degrees,	10.61	lbs.

The results of test No. 97 are fairly good, but they do not come up to the most favorable results obtained from this type of boiler. The temperature of the escaping gases is low for the existing rate of combustion. This is a favorable condition, but it is seen that the percentage of ash is high, which is an indication of inferior quality of coal. It does not always follow that a low percentage of ash indicates a high value of the combustible portion of the coal, but the fact that the most economical results based on combustible are generally obtained from coal which has a small amount of ash, is a strong indication that this is true It may be safely concluded, therefore, that the comparatively low result obtained on this test is due to a poor grade of fuel.

BOILER NO. 47.

Kind of boilers,	Vertical tubular.
Number used,	Two.
Horse-power (collective, basis 12 sq. ft.),	Two hundred and ten.
Kind of coal,	Clearfield, Bituminous.
Age,	Four years.

Dimensions.

Diameter of shell 7 1-2 feet high,	8 ft.
Diameter of fire-box,	6.5 ft.
Number of tubes in first section (collective) 3 inches outside diameter,	280
Number of tubes in second section (collective) 4 inches outside diameter,	76
Number of tubes in third section (collective) 4 1-2 inches outside diameter,	76
Length of tubes in first and second sections,	5 ft.
Length of tubes in third section,	7.5 ft.
Diameter of dome,	6 ft.
Height of dome,	7.5 ft.
Area of water-heating surface,	2,273 sq. ft.
Area of steam-heating surface,	263 sq. ft.
Area of total heating surface,	2,536 sq. ft.
Area of grate surface,	64.8 sq. ft.
Area through flue,	12 sq. ft.
Width of air spaces and metal bars in grates,	Air 1-2 in., metal 3-8 in.
Ratio of water-heating surface to grate surface,	35.1 to 1
Ratio of steam-heating surface to grate surface,	4 to 1
Ratio of grate surface to smallest tube area,	12.1 to 1

Results of Test.

	Test No. 98.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	11.5	hrs.
Coal consumed dry (including wood equivalent),	7,682	lbs.
Percentage of ash,	9.3	%
Water evaporated,	72,207	lbs.
Coal per hour,	668	lbs.
Coal per hour per square foot of grate,	10.3	lbs.
Water per hour,	6,278.9	lbs.
Water per hour per square foot of water-heating surface,	2.8	lbs.
Horse-power developed,	213.2	H.P.
Boiler pressure,	76.5	lbs.
Temperature of feed-water,	66	deg.
Temperature of escaping gases,	423	deg.
Water per pound of coal,	9.4	lbs.
Water per pound of coal from and at 212 degrees,	11.19	lbs.
Water per pound of combustible from and at 212 degrees,	12.29	lbs.

Boiler No. 47 is a fire-box vertical boiler with comparatively little steam-heating surface, and a large proportion of water-

heating surface compared with grate surface. The arrangement of tubes is quite different from the ordinary practice, the tubes being divided into three sections, arranged in concentric circles. The first section embraces the tubes in the inside. Through them the products of combustion pass in an upward direction. The second section embraces those in the next circle outside of the first section, and the products of combustion pass through these tubes in a downward direction. The third section embraces the outer circle of tubes, and the products of combustion finally pass upward through them to the flue, after first encircling the steam dome. The passage from the first section to the second section is secured by means of a combustion chamber located inside the boiler below the water line, at the upper ends of the tubes.

The proportion of water-heating surface to grate surface in this boiler is nearly double that which is found in the vertical boilers which have heretofore been considered, and the proportion of steam-heating surface to grate surface is less than half of that found in those cases. The results of the test are better, in a marked degree, than those ordinarily obtained from vertical boilers. Indeed, an evaporation of 12.29 pounds of water from and at 212 degrees per pound of combustible, is a performance which is not excelled in any case thus far recorded in the paper, whether a vertical or a horizontal boiler, and it is seldom exceeded by any boiler.

There are three things which seem to have contributed to this superior performance. First, the boiler is internally fired. Second, although of the vertical tubular type, there is an ample area of water-heating surface, and its distribution is such with an arrangement of tubes which necessitates a downward current of the gases through a part of their passage, that all of this surface is probably made efficient. Third, the rate of combustion is reasonably high, and the temperature of the escaping gases, considering the fact that the boiler is of the fire-box type, is low.

Boiler No. 48.

Kind of boiler,	Water-tube.
Number used,	One.
Horse-power (basis 12 square feet),	Seventy.
Kind of coal,	Anthracite Lehigh, Chestnut No. 2.
Age,	Six months.

Dimensions.

Number of tubes 4 inches outside diameter,	42	
Length of tubes,	16	ft.
Area of heating surface,	839	sq. ft.
Area of grate,	23	sq. ft.
Area through flue,	5.3	sq. ft.
Width of air spaces and metal bars in grates,	Air 5-16 in., metal 1-2 in.	
Height of chimney,	60	ft.
Ratio of heating surface to grate surface,	36.5	to 1.
Ratio of grate surface to flue area,	4.3	to 1.
Kind of brick setting,	Common.	

Results of Test.

	Test No. 99.	
Manner of start and stop,	Ordinary.	
Kind of run,	Continuous.	
Duration,	8.3	hrs.
Coal consumed dry (including wood equivalent),	1,576	lbs.
Percentage of ash,	14.7	%
Water evaporated,	11,292	lbs.
Coal per hour,	189.2	lbs.
Coal per hour per square foot of grate,	8.2	lbs.
Water per hour,	1,355.5	lbs.
Water per hour per square foot of heating surface,	1.6	lbs.
Horse-power developed,	47.2	H. P.
Boiler pressure,	104	lbs.
Temperature of feed-water,	68	deg.
Temperature of escaping gases,	360	deg.
Draught suction,	0.2	in.
Water per pound of coal,	7.16	lbs.
Water per pound of coal from and at 212 degrees,	8.52	lbs.
Water per pound of combustible from and at 212 degrees,	10.00	lbs.

The result of the test on boiler No. 48 is somewhat unfavorable, even for the inferior grade of anthracite coal which was used. Test No. 66 made with similar coal on a horizontal tubular boiler gave 10.72 pounds, and test No. 93, 10.78 pounds. In the case under notice, the boiler has plenty of heating surface and the heat was well absorbed, as the comparatively low temperature of the flue indicates. The rate of combustion is somewhat low for the water-tube type of boiler, and this, coupled with the possibility of an inferior quality of the fuel used, furnishes a partial and perhaps a full explanation of the low result.

Boilers Nos. 49 and 50.

Kind of boilers,	Horizontal return tubular.
Number used, each,	Two.
Horse-power (collective), each (basis 12 square feet),	Two hundred and eighty.
Kind of coal,	Nova Scotia Culm.
Age, each,	Three months.

Dimensions.

Diameter of shell, each,	72	in.
Length between heads and length of tubes,	16	ft.
Number of tubes 3 inches outside diameter, each,	140	
Number of tubes 3½ inches outside diameter, each,	100	
Area of heating surface, each,	3,347	sq. ft.
Area of grate surface, each,	84	sq. ft.
Area through tubes, each,	11.52	sq. ft.
Width of air spaces and metal bars in grates, each,	3-8	in.
Distance of grate to shell, each,	27	in.
Distance of flat bridge to shell, each,	9	in.
Character of space behind bridge wall,	Filled, inclined top.	
Ratio of heating surface to grate surface, each,	39.8	to 1
Ratio of grate surface to tube area, each,	7.3	to 1
Kind of brick setting, boiler No. 49,	Common.	
Kind of brick setting, boiler No. 50,	Passages in walls supplying air to sides of furnace and bridge wall.	

Results of Tests. (Average of two days.)

		Test No. 100. Boiler No. 49.	Test No. 101. Boiler No. 50.
Manner of start and stop and kind of run,	.	Ordinary.	Ordinary.
Duration,	hrs.	10.5	10.5
Coal consumed dry (including wood equivalent),	lbs.	12,714	12,472
Percentage of ash,	%	9.4	9.7
Water evaporated,	lbs.	91,653	90,894
Coal per hour,	lbs.	1,210.9	1,187.8
Coal per hour per square foot of grate,	lbs.	14.4	14.1
Water per hour,	lbs.	8,728.9	8,656.6
Water per hour per square foot of heating surface,	lbs.	2.6	2.6
Horse-power developed,	H. P.	298.8	296.3
Boiler pressure,	lbs.	79	79
Temperature of feed-water,	deg.	57	57
Temperature of escaping gases,	deg.	528	513
Draught suction,	in.	0.35	0.35
Water per pound of coal,	lbs.	7.21	7.28
Water per pound of coal from and at 212 degrees,	lbs.	8.65	8.74
Water per pound of combustible from and at 212 degrees,	lbs.	9.51	9.65

Boilers Nos. 49 and 50 are of the same dimensions and set in the same manner in brick-work, excepting in one particular. No. 50 has passages in the side walls which conduct air to perforated tiles in the sides of the furnace and top of the bridge wall. The total area of opening into the passages at the point where the air enters from the outside is 32 square inches. The fire-doors in each boiler are provided with registers, the openings through which have a collective area of 22 square inches. The boilers are located at the same distance from the chimney, one set being on one side of the chimney and one set on the other side, and the same plan is followed in each case in the arrangement of the flues.

The tests had for an object the determination of the economy produced by admitting air above the fuel, so far as could be determined by tests made on two different sets of boilers.

The tests were conducted simultaneously and the coal was used from the same pile, previously mixed to insure uniformity. The registers in the fire-doors were open in both sets of boilers.

The results of the tests show that the admission of air through the passages in the walls increased the evaporation per pound of coal 1 per cent., and per pound of combustible 1½ per cent. This occurred with Nova Scotia coal, which is of an extremely gaseous and smoky character.

The results of the tests as a whole show a rather low economy when compared, for example, with the work of Cumberland coal; but, as a partial explanation, it is seen that the rate of combustion is large and the temperature of the escaping gases is somewhat excessive.

BOILERS NOS. 51 AND 52.

Kind of boiler,	Horizontal return tubular.
Number used, each,	One.
Horse-power, each (basis 12 square feet),	No. 51, 150; No. 52, 130.
Kind of coal,	Nova Scotia Culm.
Age,	Three months.

Dimensions.

Diameter of shell, each,	72 in.
Length of shell between heads and length of tubes, each,	16 ft.

	Boiler No. 51.	Boiler No. 52.
Number of tubes,	140	100
Outside diameter of tubes,	3 in.	3.5 in.
Area of heating surface,	1,799 sq. ft.	1,548 sq. ft.
Area of grate surface,	42 sq. ft.	42 sq. ft.
Area through tubes,	5.8 sq. ft.	5.8 sq. ft.
Ratio of heating surface to grate surface,	42.8 to 1	36.8 to 1
Ratio of grate surface to tube area,	7.3 to 1	7.3 to 1

Width of air spaces and metal bars in grates, each,	3-8 in.
Distance of grate to shell, each,	27 in.
Distance of flat bridge to shell, each,	9 in.
Character of space behind bridge wall, each,	Filled, inclined top.
Kind of brick setting,	Common.

Results of Tests.

		Test No. 102. Boiler No. 51.	Test No. 103. Boiler No. 52.
Manner of start and stop and kind of run,	.	Ordinary.	Ordinary.
Duration,	hrs.	10.5	10 5
Coal consumed dry (including wood equivalent),	lbs.	5,562	5,518
Percentage of ash,	%	8.5	9.6
Water evaporated,	lbs.	41,660	39,537
Coal per hour,	lbs.	529.7	525.5
Coal per hour per square foot of grate,	lbs.	12.6	12.5
Water per hour,	lbs.	3,967.6	3,765.4
Water per hour per square foot of heating surface,	lbs.	2.2	2.4
Horse-power developed,	H. P.	135.8	129
Boiler pressure,	lbs.	81	81
Temperature of feed-water,	deg.	57	56
Temperature of escaping gases,	deg.	489	480
Draught suction,	in.	0.26	0.25
Water per pound of coal,	lbs.	7.49	7.17
Water per pound of coal from and at 212 degrees,	lbs.	8.99	8 60
Water per pound of combustible from and at 212 degrees,	lbs.	9.79	9.49

Tests Nos. 102 and 103 exhibit the performance of two boilers, which are duplicates of each other, with the exception of the number and size of the tubes. In one there are 140 3-inch tubes, and in the other 100 3½-inch tubes. The practical object of the tests was to determine the effect which the size of the tube has upon the economy. This object cannot fairly be said to have been attained, because the boiler which has the small tubes has such a large number of them that the heating-surface is increased a considerable amount above that of the other boiler. The test is, therefore, a determination of the effect of increased heating-surface, as well as of reduced diameter of tube.

The effect of the increased heating surface in boiler No. 51 is just what would be expected from this change of proportion, that is, a greater evaporation per pound of coal. The increase is about 4 per cent., based on coal, and about 3 per cent., based on combustible.

There appears to be some inconsistency in the results of the two tests when the temperatures of the escaping gases are examined. The temperature is the highest in the case of the boiler with the small tubes, and with the larger extent of heating surface. It is probable that these figures do not indicate the true temperatures. The two boilers were side by side, and a flue common to both connected from the smoke arch to the chimney. The temperature in each case was taken in the main flue at a point near the entrance of either boiler. The boilers were tested on different days, and doubtless the thermometer gave to some extent an average temperature of the gases supplied by both boilers, rather than the actual temperature of those from the boiler which was being tested.

Boiler No. 53.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Fifty-three.
Kind of coal,	Cumberland, Bituminous.
Age,	Several years.

Dimensions.

Diameter of shell,	48	in.
Length of shell between heads and length of tubes,	15	ft.
Number of tubes 3 inches outside diameter,	49	
Area of heating surface,	640	sq. ft.
Area of grate surface,	13.5	sq. ft.
Area through tubes,	2	sq. ft.
Area through flue,	2	sq. ft.
Distance of grate to shell,	19	in.
Distance of flat bridge to shell,	6	in.
Character of space behind bridge,	Open.	
Ratio of heating surface to grate surface,	47	to 1
Ratio of grate to tube area,	6.6	to 1
Kind of brick setting (see note),	Common.	

Results of Test.

	Test No. 104.
Manner of start and stop,	Thin fire.
Kind of run,	Continuous.
Duration,	7.6 hrs.

	Test No. 104.	
Coal consumed dry,	1,361	lbs.
Percentage of ash,	6.5	%
Water evaporated,	11,350	lbs.
Coal per hour,	177.9	lbs.
Coal per hour per square foot of grate,	13.2	lbs.
Water per hour,	1,483.7	lbs.
Water per hour per square foot of heating surface,	2.3	lbs.
Horse-power developed,	51.3	H. P.
Boiler pressure,	75	lbs.
Temperature of feed-water,	44	deg.
Temperature of escaping gases,	362	deg.
Water per pound of coal,	8.34	lbs.
Water per pound of coal from and at 212 degrees,	10.09	lbs.
Water per pound of combustible from and at 212 degrees,	10.77	lbs.

The arrangement of the furnace in boiler No. 53 was novel, and in this feature the test possesses its only interest. Several jets of superheated steam are introduced beneath the grate, and a supply of air is admitted above the fuel, the latter being forced in by means of a blower. The superheated steam is derived from the boiler and receives its superheat from a cast-iron heater placed at the back end of the furnace. The quantity of steam used by the apparatus amounted to about 8 per cent. of the whole, and this is included in the evaporation given.

This peculiar arrangement secured an almost smokeless furnace. A very small quantity of light smoke appeared for a short time after firing fresh coal, but it was almost colorless. This freedom from smoke, however, did not secure any apparent benefit in the matter of economy, for after allowing for the steam used by the apparatus, the economic result is some 20 per cent. below the ordinary results obtained in good practice.

Boiler No. 54.

Kind of boiler,	Horizontal plain cylinder.
Number used,	One.
Horse-power (basis 6 square feet),	Seventy-seven.
Age,	Several years.

Dimensions.

Number of shells,	4
Diameter of each shell,	30 in.
Length of each shell,	30.5 ft.
Area of heating surface,	464 sq. ft.
Area of grate surface,	42.7 sq. ft.
Area through flue,	6 sq. ft.
Height of chimney,	75 ft.
Width of air spaces and metal bars in grates,	Air 5-16 in., metal 3-8 in.
Ratio of heating surface to grate surface,	10.9 to 1
Ratio of grate surface to flue area,	7.1 to 1
Kind of brick setting,	Common.

Results of Tests.

		Test No. 105.	Test No. 106.
Kind of coal,		Coke.	Anthracite, Pea.
Manner of start and stop,		Thin fire.	Thin fire.
Kind of run,		Factory.	Factory.
Duration,	hrs.	10.5	11.5
Coal consumed dry,	lbs.	5,774	4,770
Percentage of ash,	%	7.7	13.2
Water evaporated,	lbs.	30,140	27,258
Coal per hour,	lbs.	549.9	414.8
Coal per hour per square foot of grate,	lbs.	12.8	9.7
Water per hour,	lbs.	2,870.5	2,370.3
Water per hour per square foot of heating surface,	lbs.	6.2	5.1
Horse-power developed,	H. P.	99.7	82.4
Boiler pressure,	lbs.	82	79
Temperature of feed-water,	deg.	39	38
Temperature of escaping gases,	deg.	Above 600	Above 600
Water per pound of coal,	lbs.	5.22	5.71
Water per pound of coal from and at 212 degrees,	lbs.	6.37	6.96
Water per pound of combustible from and at 212 degrees,	lbs.	6.87	7.97

Tests Nos. 105 and 106 show the performance of plain cylinder boilers with inferior grades of coal. The coke which is used is the product left from the manufacture of coal gas. The water evaporated per pound of coke is 8 per cent. less than the evaporation per pound of pea coal. This relation is

also that of the cost of fuel in the two cases, the price per pound being the same.

Like all plain cylinder boilers, boiler No. 54 has a small amount of heating surface. As a consequence, the temperature of the escaping gases is excessive and the economic result is low. If the result obtained with pea coal is compared with that obtained on horizontal return tubular boilers, No. 26, test No. 55, which was 9.98 pounds, it appears that the evaporation per pound of combustible is 20.1 per cent. less than is obtained in the case of the improved form of boiler. Comparing, also, test No. 105, made on this boiler with coke, with test No 108, made on a horizontal return tubular boiler with the same kind of fuel, it appears that the result obtained with the plain cylinder boiler is 32 per cent. less per pound of combustible than that obtained with the tubular boiler.

BOILER No. 55.

Kind of boilers,	Horizontal return tubular.
Number used,	Three.
Horse-power (collective, basis 12 sq. ft.),	Three hundred and twelve.
Age,	One month.

Dimensions.

Diameter of shell,	66	in.
Length between heads and length of tubes,	15	ft.
Number of tubes (collective) 3 inches outside diameter,	306	
Area of heating surfaces,	3,744	sq. ft.
Area of grate surface,	90	sq. ft.
Area through tubes,	12.6	sq. ft.
Area through flue,	4.6	sq. ft.
Height of chimney,	75	ft.
Width of air spaces and metal bars in grates,	1-2	in.
Distance of grate to shell,	24	in.
Distance of curved bridge to shell,	12	in.
Character of space behind bridge,	Open.	
Ratio of heating surface to grate surface,	41.6	to 1
Ratio of grate surface to tube area,	7.1	to 1
Ratio of grate surface to flue area,	18.3	to 1
Kind of brick setting,	Common.	

Results of Tests.

		Test No. 107.	Test No. 108.
Kind of coal,		George's Creek Cumberland.	Coke from gas coal.
Manner of start and stop,		Thin fire.	Thin fire.
Kind of run,		Factory.	Factory.
Duration,	hrs.	11.7	11.7
Coal consumed dry,	lbs.	7,330	8,541
Percentage of ash,	%	6.6	4.9
Water evaporated,	lbs.	75,119	79,371
Coal per hour,	lbs.	626.5	730
Coal per hour per square foot of grate,	lbs.	7	8.1
Water per hour,	lbs.	6,820.4	6,783.8
Water per hour per square foot of heating surface,	lbs.	1.8	1.8
Horse-power developed,	H. P.	204.1	202.9
Boiler pressure,	lbs.	84	88
Temperature of feed-water,	deg.	211	211
Temperature of escaping gases,	deg.	431	428
Draught suction,	in.	0.31	0.26
Water per pound of coal,	lbs.	10.89	9.29
Water per pound of coal from and at 212 degrees,	lbs.	11.33	9.66
Water per pound of combustible from and at 212 degrees,	lbs.	12.07	10.11

Boiler No. 55 has one characteristic which differs from the ordinary type of boiler. It is provided with a small flue and correspondingly small uptakes leading from the various boilers. As a consequence, a strong draught is required in order to secure a slow rate of combustion and a comparatively low amount of power.

The tests furnish a comparison between the best grade of Cumberland coal and coke. The water evaporated per pound of fuel is 14.7 per cent. less with coke than with the standard grade of coal. On the basis of the prices which applied to this case, the coal being $3.25 per ton and the coke $3.00 per ton (2,000 pounds), the cost of coal required to produce a given amount of steam is 7.4 per cent. less than the cost of coke.

The economic result of the test with Cumberland coal is excellent, in spite of the somewhat low rate of combustion and a somewhat high temperature of the escaping gases.

Boiler No. 56.

Kind of boilers,	Horizontal return tubular.
Number used,	Two.
Horse-power (collective, basis 12 sq. ft.),	One hundred and seventy-five.
Kind of coal,	George's Creek Cumberland.
Age,	Ten years.

Dimensions.

Diameter of shell,	54	in.
Length between heads and length of tubes,	15	ft.
Number of tubes (collective) 3 inches outside diameter,	160	
Area of water-heating surface,	1,980	sq.
Area of steam-heating surface,	120	sq.
Area of total heating surface,	2,100	sq.
Area of grate surface,	49.3	sq.
Area through tubes,	6.6	sq.
Area through flue,	6	sq.
Width of air spaces and metal bars in grates,	Air 7-16 in., metal 5-16	
Distance of grate to shell,	19	in.
Distance of flat bridge wall to shell,	5	in.
Character of space behind bridge,	Open.	
Ratio of water-heating surface to grate surface,	40	to
Ratio of grate surface to tube area,	7.5	to
Kind of brick setting,	Common	

Results of Test. (Average of two.)

	Test No. 109	
Manner of start and stop and kind of run,	Ordinary	
Duration,	11.5	hrs.
Coal consumed dry (including wood equivalent),	6,288	lbs.
Percentage of ash,	6.5	%
Water evaporated,	58,993	lbs.
Coal per hour,	546.8	lbs.
Coal per hour per square foot of grate,	11.1	lbs.
Water per hour,	5,134.2	lbs.
Water per hour per square foot of water-heating surface,	2.6	lbs.
Horse-power developed,	177.6	H. P.
Boiler pressure,	65	lbs.
Temperature of feed-water,	57	deg.
Temperature of escaping gases,	408	deg.
Draught suction,	0.35	in.
Percentage of moisture in steam,	2.2	%
Water per pound of coal,	9.3	lbs.
Water per pound of coal from and at 212 degrees,	11.2	lbs.
Water per pound of combustible from and at 212 degrees,	11.9	lbs.

Test No. 109 exhibits the performance of a typical horizontal return tubular boiler using a high grade of Cumberland coal. The boiler had been in service several years, but the inside surfaces were free from scale and the boiler was in every way in good condition. The rate of combustion is reasonably high. The temperature of the gases is not excessive and the economic results are favorable.

The steam-heating surface in this boiler consisted of the upper surface of the shell, and the escaping gases passed over it on their way to the flue. It is probable that this surface was inefficient, its location being favorable for the deposit of soot and ashes and the formation of a non-conducting covering.

BOILER No. 57.

Kind of boilers,	Water-tube.
Number used,	Two.
Horse-power (collective, basis 12 sq. ft.),	Two hundred and sixty.
Kind of coal,	George's Creek Cumberland.
Age,	Two years.

Dimensions.

Number of tubes 4 inches outside diameter,	144	
Length of tubes,	18	ft.
Area of heating surface,	3,126	sq. ft.
Area of grate surface,	50	sq. ft.
Area through flue,	11	sq. ft.
Height of chimney,	80	ft.
Width of air spaces and metal bars in grates,	Air 1-2 in., metal 11-16 in.	
Ratio of heating surface to grate surface,	62.5	to 1
Ratio of grate surface to flue area,	4.5	to 1
Area of heating surface in flue heater,	1,600	sq. ft.
Kind of brick setting,	Passages in walls supplying air to sides of furnace.	

Results of Tests.

		Test No. 110.	Test No. 111.
		Heater in use.	Heater not in use.
Manner of start and stop and kind of run,	.	Ordinary.	Ordinary.
Duration,	hrs.	11.5	11.5
Coal consumed dry (including wood equivalent),	lbs.	8,743	9,694
Percentage of ash,	%	7.5	7.7
Water evaporated,	lbs.	84,078	82,725
Coal per hour,	lbs.	760.3	843
Coal per hour per square foot of grate,	lbs.	15.2	16.8
Water per hour,	lbs.	7,310.4	7,193.2
Water per hour per square foot of heating surface,	lbs.	2.3	2.3
Horse-power developed,	H. P.	247	243.5
Boiler pressure,	lbs.	68	67
Temperature of feed-water entering heater,	deg.	84	-
Temperature of feed-water entering boiler,	deg.	196	82
Temperature of escaping gases leaving boiler,	deg.	435	452
Temperature of escaping gases leaving heater,	deg.	279	-
Draught suction,	in.	0.25	0.27
Percentage of moisture in steam,	%	1.3	-
Water per pound of coal,	lbs.	9.62	8.53
Water per pound of coal from and at 212 degrees,	lbs.	10.10	9.95
Water per pound of combustible from and at 212 degrees,	lbs.	10.92	10.79

NOTE. — The coal when fired contained 5 per cent. of moisture.

The principal interest which attaches to the tests on boiler No. 57 is the effect upon the economy of the boiler produced by the use of a heater in the flue. The area of heating surface exposed by the heater to the escaping gases is about one-half of the total heating surface of the boilers. This surface consisted of vertical cast-iron pipes over which a series of scrapers, operated by power, are continually moving up and down. The heater reduced the temperature of the gases from 435 to 279 degrees, or 156 degrees, and increased the temperature of the water from 84 degrees to 196 degrees, or 112 degrees, the

result of which was an increase in the evaporation per pound of coal of 12.8 per cent.

Looking at the general performance of the boilers it appears that the economy is inferior to that of many shell boilers considered in the paper. The proportion of heating surface to grate surface is ample, so also is the rate of combustion. The temperature of the escaping gases is not excessive. The quality of the coal, judging from the low percentage of ash, is excellent. With all these conditions, which would ordinarily be considered favorable, it is difficult to assign a cause for the somewhat unfavorable result, unless it be the loss produced by the admission of air over the fuel through the passages in the walls and that which may have entered through openings in the brick-work, due to the somewhat long service to which the boiler had been subjected. The admission of air in this manner makes the actual loss from the waste heat in the gases greater than that apparently indicated by the temperature.

BOILER No. 58.

Kind of boilers,	Vertical tubular (rolling-pin).
Number used,	Two.
Horse-power (collective, basis 10 sq. ft.),	Two hundred and eighty.
Kind of coal,	George's Creek Cumberland.
Age,	Twelve years.

Dimensions.

Diameter of main shell,	90	in.
Diameter of drum and water leg,	30	in.
Length of main shell and tubes,	10	ft.
Number of tubes (collective) 2 inches outside diameter,	496	
Area of water-heating surface,	1,880	sq. ft.
Area of steam-heating surface,	924	sq. ft.
Area of grate surface,	90	sq. ft.
Area through tubes,	8.2	sq. ft.
Width of air spaces and metal bars in grates,	Air 1-2 in., metal 5-8 in.	
Height of chimney,	80	ft.
Ratio of water-heating surface to grate surface,	20.9	to 1
Ratio of steam-heating surface to grate surface,	10.3	to 1
Ratio of grate surface to tube area,	11	to 1
Area of heating surface in flue heater,	1,600	sq. ft.
Kind of brick setting,	Common.	

Results of Tests.

	Test No. 112.	Test No. 113.
	Heater in use.	Heater not in use.
Manner of start and stop and kind of run, .	Ordinary.	Ordinary.
Duration, ... hrs.	11.5	11.5
Coal consumed dry (including wood equivalent), ... lbs.	7,856	10,282
Percentage of ash, ... %	8	8.4
Water evaporated, ... lbs.	72,002	72,959
Coal per hour, ... lbs.	683.1	894.1
Coal per hour per square foot of grate, . lbs.	7.6	9.9
Water per hour, ... lbs.	6,261	6,344.3
Water per hour per square foot of water-heating surface, ... lbs.	3.3	3.4
Horse-power developed, ... H. P.	210.3	213.6
Boiler pressure, ... lbs.	58	59
Temperature of feed-water entering heater, deg.	88	–
Temperature of feed-water entering boiler, deg.	225	85
Temperature of escaping gases leaving boiler, ... deg.	618	645
Temperature of escaping gases leaving heater, ... deg.	365	–
Number of degrees of superheating, . . deg.	50	52
Draught suction, ... in.	0.09	–
Water per pound of coal, ... lbs.	9.16	7.10
Water per pound of coal from and at 212 degrees, ... lbs.	9.21	8.23
Water per pound of combustible from and at 212 degrees, ... lbs.	10.00	8.99

NOTE. — The coal when fired contained 3 per cent. of moisture.

The interest in the tests on boiler No. 58, as in those of the preceding boiler, centres in the effect produced by the flue heater. They are of especial interest since the boiler is of the vertical type and discharges a large amount of waste heat into the flue. The heater consisted of vertical cast-iron pipes with scrapers, which add nearly as much heating surface to the plant as the whole area of water-heating surface in the boilers. The temperature of the escaping gases was reduced from 618 degrees to 365 degrees, that is, 253 degrees. The temperature of the feed-water was raised from 88 degrees to 225 degrees, that is,

137 degrees. The effect of the heater was to increase the evaporation per pound of coal 29 per cent.

Considering the results of test No. 112, as applied to the plant as a whole, the evaporation per pound of combustible from and at 212 degrees is 11.54 pounds. Allowing now for the extreme effect which would be produced by the superheat in the steam, this result would be increased to the equivalent of about 12 pounds, a result which corresponds quite closely to the highest figures obtained from horizontal tubular boilers, as given in the paper.

BOILER No. 59.

Kind of boilers,	Hor. ret. tub. (double-deck).
Number used,	Four.
Horse-power (collective, basis 15 sq. ft.),	Two hundred and ninety.
Kind of coal,	Cumberland.
Age,	Six years.

Dimensions.

Diameter of lower shell,	48	in.
Diameter of upper shell,	30	in.
Length of shells and tubes,	14	ft.
Number of tubes (collective) 3 inches outside diameter,	320	
Area of water-heating surface,	4,058	sq. ft.
Area of steam-heating surface,	280	sq. ft.
Area of grate surface,	70	sq. ft.
Area through tubes,	13.2	sq. ft.
Area through flue,	9	sq. ft.
Height of chimney,	80	ft.
Width of air spaces and metal bars in grates,	Air 5-8 in., metal 1 in.	
Ratio of water-heating surface to grate surface,	58	to 1
Ratio of steam-heating surface to grate surface,	4	to 1
Ratio of grate surface to tube area,	5.3	to 1
Ratio of grate surface to flue area,	7.8	to 1
Area of heating surface in flue heater,	1,920	sq. ft.
Kind of brick setting,	Common.	

Results of Tests.

		Test No. 114.	Test No. 115.
Manner of start and stop and kind of run,	.	Heater in use. Ordinary.	Heater not in use. Ordinary.
Duration,	hrs.	12.5	12.5
Coal consumed dry (including wood equivalent),	lbs.	10,659	10,946
Percentage of ash,	%	7.6	7
Water evaporated,	lbs.	106,598	102,261
Coal per hour,	lbs.	852.7	875.6
Coal per hour per square foot of grate,	lbs.	12.2	12.5
Water per hour,	lbs.	8,527.8	8,180.8
Water per hour per square foot of water-heating surface,	lbs.	2.1	2
Horse-power developed,	H. P.	289.9	277.8
Boiler pressure,	lbs.	77	75
Temperature of feed-water entering heater,	deg.	79	–
Temperature of feed-water entering boiler,	deg.	145	79
Temperature of escaping gases leaving boiler,	deg.	361	342
Temperature of escaping gases leaving heater,	deg.	254	–
Draught suction,	in.	0.17	0.22
Water per pound of coal,	lbs.	10.00	9.34
Water per pound of coal from and at 212 degrees,	lbs.	11.05	10.95
Water per pound of combustible from and at 212 degrees,	lbs.	11.96	11.78

NOTE. — The coal when fired contained 5 per cent. of moisture.

The tests on boiler No. 59 show the economy that may be secured by the use of a flue heater in a case where there is ample heating surface in the boiler and a low degree of waste heat. The heater consists of vertical cast-iron pipes with scrapers, having an exterior surface amounting to 50 per cent. of the area of the heating surface of the boiler. The temperature of the gases is reduced from 361 degrees to 254 degrees, or 107 degrees, and the temperature of the water is raised from 79 degrees to 145 degrees, or 66 degrees, and this secures an increased evaporation of 7 per cent. If test No. 114 is applied to the operation of the plant as a whole, the evapora-

tion per pound of combustible from and at 212 degrees becomes 12.68 pounds. This figure is higher, with a single exception, than any result given in the paper, and it shows what may be secured by the employment of an ample area of surface, arranged in such a manner to properly absorb the heat. The result is obtained upon a boiler, which, without the heater, as the test shows, is inferior in point of economy to the best type of horizontal tubular boiler.

Boiler No. 60.

Kind of boilers,	Horizontal return tubular.
Number used,	Two.
Horse-power (collective, basis 12 sq. ft.),	One hundred and fifty-eight.
Kind of coal,	Two parts Anthracite Lehigh, Buckwheat, one part Clearfield, Bituminous.
Age,	Five years.

Dimensions.

Diameter of shell,	60	in.
Length between heads and length of tubes,	15	ft.
Number of tubes (collective) 3 inches outside diameter,	132	
Area of heating surface,	1,894	sq. ft.
Area of grate surface,	50	sq. ft.
Area through tubes,	5.4	sq. ft.
Height of chimney,	110	ft.
Width of air spaces and metal bars in grates,	Air 3-8 in., metal 7-16 in.	
Ratio of heating surface to grate surface,	37.9	to 1
Ratio of grate surface to tube opening,	9.3	to 1
Area of heating surface in flue heater,	1,600	sq. ft.
Kind of brick setting,	Passages in walls admitting air to sides of furnace and bridge wall.	

Results of Tests.

		Test No. 116.	Test No. 117.
Manner of start and stop and kind of run,	.	Heater in use. Ordinary.	Heater not in use. Ordinary.
Duration,	hrs.	12	12
Coal consumed dry (including wood equivalent),	lbs.	5,901	6,564
Percentage of ash,	%	11.8	11.8
Water evaporated,	lbs.	51,955	52,303
Coal per hour,	lbs.	491.7	547
Coal per hour per square foot of grate,	lbs.	9.8	10.9
Water per hour,	lbs.	4,329.5	4,358.5
Water per hour per square foot of heating surface,	lbs.	2.3	2.3
Horse-power developed,	H. P.	145	146.3
Boiler pressure,	lbs.	77	77
Temperature of feed-water entering heater,	deg.	95	–
Temperature of feed-water entering boiler,	deg.	175	93
Temperature of escaping gases leaving boiler,	deg.	346	399
Temperature of escaping gases leaving heater,	deg.	231	–
Water per pound of coal,	lbs.	8.80	7.97
Water per pound of coal from and at 212 degrees,	lbs.	9.42	9.22
Water per pound of combustible from and at 212 degrees,	lbs.	10.70	10.45

NOTE. — The coal when fired contained 2½ per cent. of moisture.

Boiler No. 60 differed from the ordinary boiler in being fitted with pipes underneath the shell through which the water passed on its way to the boiler. The surface exposed by these pipes amounted to 180 square feet, and this is included in the quantity given in the table. Besides the air which entered through the side walls, a considerable amount was also admitted through the fire-doors which are especially arranged for this purpose.

The tests show the effect produced by a flue heater upon the economy in the case of an ordinary tubular boiler in which the temperature of the escaping gases was low at the outset.

The heater consists of cast-iron pipes with scrapers, which presented an area nearly as large as the whole area of heating surface in the boilers. A reduction of 145 degrees occurred in the temperature of the gases, and an increase of 80 degrees in the temperature of the feed-water, and the evaporation per pound of coal was increased by the heater 10.5 per cent.

The economic result produced without the heater is about the same as that obtained in ordinary practice with this grade of mixed fuel.

BOILER No. 61.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Sixty-five.
Kind of coal,	Bituminous Walston (similar to Pittsburgh coal).
Age,	Four years.

Dimensions.

Diameter of shell,	54	in.
Length between heads and length of tubes,	12	ft.
Number of tubes 3 inches outside diameter,	71	
Area of heating surface,	783	sq. ft.
Area of grate surface,	24	sq. ft.
Area through tubes,	2.9	sq. ft.
Area through flue,	3.1	sq. ft.
Height of chimney,	50	ft.
Width of air spaces and metal bars in grates,	Air 5-16 in., metal 1⅛ in.	
Distance of grate to shell,	18	in.
Distance of flat bridge to shell,	7	in.
Character of space behind bridge,	Open.	
Ratio of heating surface to grate surface,	32.2	to 1
Ratio of grate surface to tube area,	8.3	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No. 118.	
Manner of start and stop,	Ordinary, with preliminary heating.	
Kind of run,	Continuous.	
Duration,	8.6	hrs.
Coal consumed dry (including wood equivalent),	2,562	lbs.

	Test No. 118.	
Percentage of ash,	7.3	%
Water evaporated,	20,395	lbs.
Coal per hour,	296	lbs.
Coal per hour per square foot of grate,	12.3	lbs.
Water per hour,	2,357.7	lbs
Water per hour per square foot of heating surface,	3	lbs.
Horse-power developed,	79.7	H.P.
Boiler pressure,	77	lbs.
Temperature of feed-water,	86	deg.
Temperature of escaping gases,	572	deg.
Water per pound of coal,	7.96	lbs.
Water per pound of coal from and at 212 degrees,	9.27	lbs.
Water per pound of combustible from and at 212 degrees,	10.00	lbs.

The test on boiler No. 61 shows the performance of a horizontal return tubular boiler of good proportions, when burning Walston coal, which is of similar grade to that known as Pittsburgh coal. The main interest in the test lies in the kind of coal used. There is a very high temperature of the escaping gases, which is an indication that the boiler did not secure the best results attainable from this class of fuel. Judging from the effect upon the economy produced by a flue heater, the excessive temperature represents a loss of at least 10 per cent. An evaporation of 11 pounds from and at 212 degrees per pound of combustible ought to be obtained, therefore, from this fuel, under favorable conditions. Such a result is about 10 per cent. below the best figures given in the paper for boilers working with Cumberland coal.

Boiler No. 62.

Kind of boilers,	Horizontal return tubular.
Number used,	Three.
Horse-power (collective, basis 12 sq. ft.),	Two hundred and seventy-five.
Age,	Six years.

Dimensions.

Diameter of shell,	60	in.
Length between heads and length of tubes,	17	ft.
Number of tubes (collective) 3 inches outside diameter,	231	

Area of heating surface,	3,306 sq. ft.
Area of grate surface,	69.8 sq. ft.
Area through tubes,	9.5 sq. ft.
Area through flue,	10.1 sq. ft.
Height of chimney,	98 ft.
Width of air spaces and metal bars in grates,	3-8 in.
Distance of grate to shell,	19 in.
Distance of flat bridge wall to shell,	12 in.
Character of space behind bridge wall,	Filled, level covering.
Ratio of heating surface to grate surface,	47.4 to 1
Ratio of grate surface to tube area,	7.3 to 1
Kind of brick setting,	Common.

Results of Tests.

		Test No. 119.	Test No. 120.
Kind of coal,		George's Creek Cumberland.	Philadelphia and Reading, Anthracite, Broken.
Manner of start and stop and kind of run,		Ordinary.	Ordinary.
Duration,	hrs.	12	11.7
Coal consumed dry (including wood equivalent),	lbs.	5,639	9,765
Percentage of ash,	%	8.3	10.7
Water evaporated,	lbs.	50,263	79,868
Coal per hour,	lbs.	469.9	832.5
Coal per hour per square foot of grate,	lbs.	6.7	11.9
Water per hour,	lbs.	4,204.3	6,811.6
Water per hour per square foot of heating surface,	lbs.	1.3	2.1
Horse-power developed,	H. P.	141.3	228.7
Boiler pressure,	lbs.	88	86
Temperature of feed-water,	deg.	94	96
Temperature of escaping gases,	deg.	340	428
Draught suction,	in.	0.09	0.17
Percentage of moisture in steam,	%	0.86	0.49
Water per pound of coal,	lbs.	8.91	8.18
Water per pound of coal from and at 212 degrees,	lbs.	10.34	9.46
Water per pound of combustible from and at 212 degrees,	lbs.	11.24	10.60

NOTE. — The Cumberland coal when fired contained 3 per cent of moisture.

The tests on boiler No. 62 cannot be used for a fair comparison of the performance of the two fuels which were burned,

because of the large difference in the rates of combustion in the two cases. The boiler has a large extent of heating surface. The test with Cumberland coal shows a favorable result so far as the temperature of the gases is concerned, but a somewhat unfavorable result in point of economy. The rate of combustion is low, and this doubtless gave rise to neglect of the fires. In the case of the test with anthracite coal the rate of combustion is too high for the best results, and a considerable loss was experienced by the somewhat excessive temperature of the gases which existed.

Boiler No. 63.

Kind of boiler,	Hor. tub., detached furnace.
Number used,	One.
Horse-power (basis 12 square feet),	Two hundred and seventy.
Age,	Two months.

Dimensions.

Diameter of shell,	96	in.
Length between heads and length of tubes,	20	ft.
Number of tubes 3 inches outside diameter,	206	
Area of heating surface,	3,242	sq. ft.
Area of grate surface,	56	sq. ft.
Area through tubes,	8.5	sq. ft.
Area through flue,	9.7	sq. ft
Height of chimney,	98	ft.
Width of air spaces and metal bars in grates,	Air 3-8 in., metal 1-2 in.	
Ratio of heating surface to grate surface,	57.9	to 1
Ratio of grate surface to tube area,	6.7	to 1
Kind of brick setting,	(See memorandum.)	

Results of Tests.

		Test No. 121.	Test No. 122.	Test No. 123.	Test No. 124.
Kind of fuel,		Philadelphia and Reading, Anthracite, Broken.	George's Creek Cumberland.	4 pts. Geo.'s Creek Cumberl'd, 6 pts. Anthracite Screenings.	Crude Petroleum.
Manner of start and stop and kind of run,		Ordinary.	Ordinary.	Ordinary.	*
Duration,	hrs.	12.4	10.8	10.9	4.6
Fuel consumed dry (including wood equivalent),	lbs.	8,242	7,300	7,450	2,327
Percentage of ash,	%	10.3	8.3	8.7	–
Water evaporated,	lbs.	72,629	69,284	66,671	28,751
Fuel per hour,	lbs.	665.2	675.9	683.5	504.1
Fuel per hour per square foot grate,	lbs.	11.9	12.1	12.2	–
Water per hour,	lbs.	5,861.5	6,385.4	6,102.2	6,228
Water per hour per square foot heating surface,	lbs.	1.8	2	1.9	1.9
Horse-power developed,	H.P.	196.1	214.6	204.8	209.2
Boiler pressure,	lbs.	63	85	85	78
Temperature of feed-water,	deg.	94	95	96	93
Temperature of escaping gases,	deg.	321	397	367	429
Draught suction,	in.	0.25	0.20	0.31	–
Percentage of moisture in steam,	%	–	0.43	0.49	–
Water per pound of fuel,	lbs.	8.81	9.49	8.93	Gross 12.36 Net 11.80
Water per pound of fuel from and at 212 degrees,	lbs.	10.16	10.99	10.33	Net 13.66
Water per pound of combustible from and at 212 degrees,	lbs.	11.33	11.99	11.30	–

* Afternoon period of the day's run starting with hot furnace and boiler.

NOTE. — The Cumberland coal when fired contained 3 per cent. of moisture and the mixed fuel 4 per cent.

Boiler No. 63 differs from the ordinary tubular boiler in being provided with a detached brick furnace placed at the front end of the boiler. The position of the furnace with reference to the boiler is precisely that of the fire-box of a locomotive boiler. After the products of combustion have passed forward through the tubes, they return beneath the

shell and enter an underground flue leading to the chimney. Direct radiation of heat from the coal in the furnace to the tube sheet is prevented by means of a brick arch which overhangs the grate.

This boiler has a large shell, long tubes, and a large extent of heating surface compared with grate surface.

The tests show the relative performance of different kinds of fuel, and especially the result produced by the use of crude petroleum. The petroleum is the "residuum" of the oil, or that left after the kerosenes have been removed. It is supplied to the burner by a steam pump, and discharged from the burner by means of a steam jet. The amount of steam used by pump and jet was 4½ per cent. of that generated by the boiler. The net evaporation from and at 212 degrees per pound of oil is 13.66 pounds. This quantity is 34 per cent. more than the evaporation per pound of anthracite coal, and 24 per cent. more than the evaporation per pound of Cumberland coal. With Cumberland coal at $4.50 per ton (2,240 pounds), the price of oil required to make the cost of fuel for producing a given amount of steam the same in both cases is 1.8 cents per gallon.

The result obtained with the "residuum" employed here is no doubt inferior to that which would be obtained from the crude oil itself. This oil came from the Pennsylvania oil-fields. A test made on another horizontal tubular boiler of the ordinary type, which was 6 feet in diameter and 14 feet long, and contained 71 4-inch tubes, having 39 square feet of heating surface to 1 of grate, gave a net evaporation of 15 pounds of water from and at 212 degrees per pound of oil, the oil being obtained from wells in Canada.

Comparing the results of the coal test with each other, the evaporation per pound of Cumberland coal is 8.1 per cent. greater than that of anthracite coal; and the evaporation per pound of the mixture is 1 per cent. greater. Basing the comparison on the cost of fuel, the cost of coal required to produce a given amount of steam is 8 per cent. less when Cumberland coal is used, and 23.5 per cent. less when mixed

fuel is used, than that of anthracite coal. The prices on which these figures are obtained, per ton of 2,240 pounds, are $4.50 each for anthracite and Cumberland, and $2.75 for screenings.

Boiler No. 64.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Ninety-five.
Kind of coal,	Bituminous, Ohio Lump.
Age,	Several years.

Dimensions.

Diameter of shell,	72	in.
Length between heads and length of tubes,	14	ft.
Number of tubes 4 inches outside diameter,	71	
Area of heating surface,	1,144	sq. ft.
Area of grate surface,	29.2	sq. ft.
Area through tubes,	5.4	sq. ft.
Area through flue,	7	sq. ft.
Height of chimney,	60	ft.
Width of air spaces and metal bars in grates,	3-8	in.
Distance of grate to shell,	24	in.
Distance of curved bridge to shell,	8	in.
Character of space behind bridge,	Filled, level covering.	
Ratio of heating surface to grate surface,	39.2	to 1
Ratio of grate surface to tube area,	5.4	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No. 125.	
Manner of start and stop,	Ordinary, with preliminary heating.	
Kind of run,	Continuous.	
Duration,	9.7	hrs.
Coal consumed dry (including wood equivalent),	3,111	lbs.
Percentage of ash,	7.6	%
Water evaporated,	22,650	lbs.
Coal per hour,	319.1	lbs.
Coal per hour per square foot of grate,	10.9	lbs.
Water per hour,	2,323.1	lbs.
Water per hour per square foot of heating surface,	2	lbs.
Horse-power developed,	79.9	H. P.

	Test No. 125.
Boiler pressure,	74.8 lbs.
Temperature of feed-water,	64.5 deg.
Temperature of escaping gases,	501 deg.
Water per pound of coal,	7.28 lbs.
Water per pound of coal from and at 212 degrees,	8.64 lbs.
Water per pound of combustible from and at 212 degrees,	9.35 lbs.

The interest which attaches to the test of boiler No. 64 lies in the use of Ohio lump coal. Owing to the high temperature of the escaping gases, which was 501 degrees, it is evident that the full economy which can be obtained from this fuel was not realized. Probably an evaporation of 10 pounds of water from and at 212 degrees per pound of combustible represents the result which would have been obtained under favorable conditions. This performance is 16⅔ per cent. below the best figures given in the paper for boilers working with Cumberland coal.

It is to be noted that the temperature of the waste gases in this case and that obtained in the case of boiler No. 61, using Pittsburgh coal, are somewhat excessive when the proportion of heating surface to grate surface and the rate of combustion are considered. Both of these coals are what is termed "free burning," that is to say, they do not have so great a tendency to coke as that possessed by bituminous coals which are used in the Eastern States. The quality of free burning has doubtless much to do with the production of a high flue temperature. A characteristic of all bituminous coals is the tendency to produce a high flue temperature, and it points to the proportioning of the boiler in such a way as to obtain a larger area of heating surface than is used when anthracite coal is employed.

Boiler No. 65.

Kind of boilers,	Water-tube.
Number used,	Two.
Horse-power (collective, basis 12 sq. ft.),	Eighty-eight.
Kind of coal,	Anthracite Lackawanna, Egg.
Age,	One year.

Dimensions.

Number of tubes 3½ inches outside diameter,	78	
Length of tubes,	14	ft.
Area of heating surface,	1,058	sq. ft.
Area of grate surface,	42.8	sq. ft.
Area through flue,	4.9	sq. ft.
Width of air spaces and metal bars in grates,	Air 5-8 in., metal 1 in.	
Height of chimney,	70	ft.
Ratio of heating surface to grate surface,	24.7	to 1
Ratio of grate surface to flue area,	8.7	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No. 126.	
Manner of start and stop and kind of run,	Ordinary, with preliminary heating.	
Duration,	10.9	hrs.
Coal consumed (including wood equivalent),	6,808	lbs.
Percentage of ash,	11.4	%
Water evaporated,	54,014	lbs.
Coal per hour,	621.8	lbs.
Coal per hour per square foot of grate,	14.5	lbs.
Water per hour,	4,933.1	lbs.
Water per hour per square feet of heating surface,	4.7	lbs.
Horse-power developed,	164.9	H. P.
Boiler pressure,	72.9	lbs.
Temperature of feed-water,	97	deg.
Temperature of escaping gases,	513	deg.
Draught suction,	0.23	in.
Percentage of moisture in steam,	1.6	%
Water per pound of coal,	7.93	lbs.
Water per pound of coal from and at 212 degrees,	9.14	lbs.
Water per pound of combustible from and at 212 degrees,	10.31	lbs.

Test No. 126 exhibits the performance of a water-tube boiler which was deficient in heating surface and which was worked to a high capacity. The temperature of the escaping gases is excessive, but not more so than would be expected, considering the high rate of combustion and the small proportion of heating surface. With these unfavorable conditions the evaporation per pound of combustible from and at 212 degrees is 10.31 pounds, which is some 7 per cent. below the results ob-

tained in many of the best cases recorded in the paper for anthracite coal. A reduction of grate surface here of say one-third, still preserving the same rate of combustion, namely, 14.5 pounds of coal per square feet of grate per hour, would doubtless have brought the result up to the standard of good economy.

Boiler No. 66.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Thirty.
Kind of coal,	Anthracite Wilkesbarre, Broken.
Age,	One year.

Dimensions.

Diameter of shell,	42	in.
Length between heads and length of tubes,	10	ft.
Number of tubes 2 in. outside diameter below water-line,	67	
Number of tubes 2 in. outside diameter above water-line,	68	
Area of water-heating surface,	369.3	sq. ft.
Area of steam-heating surface,	318.8	sq. ft.
Area of grate surface,	9.2	sq. ft.
Tube area below water-line,	1.1	sq. ft
Flue area,	2.2	sq. ft.
Height of chimney,	30	ft.
Width of air spaces and metal bars in grates,	5-8	in.
Ratio of water-heating surface to grate surface,	40.3	to 1
Ratio of steam-heating surface to grate surface,	33.6	to 1
Ratio of grate surface to tube area below water-line,	8.2	to 1
Kind of brick setting,	Common, with fan draught.	

Results of Test.

	Test No. 127.	
Manner of start and stop,	Ordinary, with preliminary heating.	
Kind of run,	Continuous.	
Duration,	8	hrs.
Coal consumed (including wood equivalent),	1,453	lbs.
Percentage of ash,	9.5	%
Water evaporated,	10,341	lbs.
Coal per hour,	181.5	lbs.
Coal per hour per square foot of grate,	20	lbs.

	Test No. 127.	
Water per hour,	1,291.8	lbs.
Water per hour per square foot of water-heating surface,	3.5	lbs.
Horse-power developed,	45.5	H. P.
Boiler pressure,	66	lbs.
Temperature of feed-water,	36	deg.
Temperature of escaping gases entering upper tubes,	558	deg.
Temperature of escaping gases leaving upper tubes,	394	deg.
Number of degrees of superheating,	30	deg.
Water per pound of coal,	7.12	lbs.
Water per pound of coal from and at 212 degrees,	8.64	lbs.
Water per pound of combustible from and at 212 degrees,	9.55	lbs.

Boiler No. 66 is a novelty for this type of boiler, inasmuch as it is provided with a large extent of steam-heating surface, obtained by filling the space above the water-line with tubes. The products of combustion, after passing through the lower tubes in the usual manner, return through the superheating tubes and enter the chimney at the rear end. The steam on leaving the boiler enters a vertical drum 30 inches diameter, 8 feet high. The temperature of the steam was obtained at the point of leaving the drum. The interest in this test lies in the effect produced by the steam-heating surface. The temperature of the gases in passing over this surface was reduced 164 degrees, and this served to dry the moisture in the steam and to superheat it 30 degrees at the point where the temperature was taken, and probably 50 degrees at the point of leaving the boiler.

The general results of the test do not appear to be very good, but probably as good as other boilers of small size produce which furnish superheated steam.

Boiler No. 67.

Kind of boiler,	Water-tube.
Number used,	One.
Horse-power (basis 12 square feet),	Eighty.
Kind of coal,	Anthracite Lackawanna Chestnut No. 2.
Age,	Six months.

Dimensions.

Number of tubes 4 inches outside diameter,	48	
Length of tubes,	15	ft.
Area of water-heating surface,	848	sq. ft.
Area of steam heating surface,	114	sq. ft.
Area of total heating surface,	962	sq. ft.
Area of grate surface,	27	sq. ft.
Area through flue,	3.7	sq. ft.
Height of chimney,	70	ft.
Width of air spaces and metal bars in grates,	Air 3-8 in., metal 1-2 in.	
Ratio of water-heating surface to grate surface,	31.4	to 1
Ratio of steam-heating surface to grate surface,	4.2	to 1
Ratio of grate surface to flue area,	7.4	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No 138.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	10.1	hrs.
Coal consumed (including 91 pounds leather scraps, 91 pounds coal),	2,972	lbs.
Percentage of ash,	16.4	%
Water evaporated,	23,396	lbs.
Coal per hour,	294	lbs.
Coal per hour per square foot of grate,	10.9	lbs.
Water per hour,	2,314.1	lbs.
Water per hour per square foot of water-heating surface,	2.7	lbs.
Horse-power developed,	73.9	H. P.
Boiler pressure,	84	lbs.
Temperature of feed-water,	150	deg.
Temperature of escaping gases,	428	deg.
Draught suction,	0.12	in.
Water per pound of coal,	7.87	lbs.
Water per pound of coal from and at 212 degrees,	8.66	lbs.
Water per pound of combustible from and at 212 degrees,	10.36	lbs.

NOTE. — When the water was carried below the ordinary level, the steam was superheated a few degrees. Ordinarily the thermometer failed to show any superheat.

The test on boiler No. 67 shows a favorable result, considering the kind of coal employed and the somewhat high temperature of the escaping gases. Comparing this test with the

one on water-tube boiler No. 48, made with similar coal, the difference in the temperature of the escaping gases is noticeable. That test showed 555 degrees and gave a lower evaporation.

Boiler No. 68.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	Twenty-seven.
Kind of coal,	Bituminous Walston (similar to Pittsburgh).
Age,	Several years.

Dimensions.

Diameter of shell,	42	in.
Length between heads and length of tubes,	10	ft.
Number of tubes 3 inches outside diameter,	36	
Area of heating surface,	322	sq. ft.
Area of grate surface,	14.4	sq. ft.
Area through tubes,	1.5	sq. ft.
Area through flue,	2.2	sq. ft.
Height of chimney,	56	ft.
Width of air spaces and metal bars in grates,	Air 5-16 in., metal 11-16 in.	
Distance of grate to shell,	21	in.
Distance of flat bridge to shell,	8	in.
Character of space behind bridge,	Filled, level covering.	
Ratio of heating surface to grate surface,	22.3	to 1
Ratio of grate surface to tube area,	9.8	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No. 129.	
Manner of start and stop,	Ordinary, with preliminary heating.	
Kind of run,	Continuous.	
Duration,	8.3	hrs.
Coal consumed dry (including wood equivalent),	1,134	lbs.
Percentage of ash,	7.6	%
Water evaporated,	9,519	lbs.
Coal per hour,	137.4	lbs.
Coal per hour per square foot of grate,	9.52	lbs.
Water per hour,	1,153.3	lbs.

	Test No. 129.	
Water per hour per square foot of heating surface,	3.6	lbs.
Horse-power developed,	34.9	H. P.
Boiler pressure,	82.2	lbs.
Temperature of feed-water,	205.3	deg.
Temperature of escaping gases,	445	deg.
Percentage of moisture in steam,	0.2	%
Water per pound of coal,	8.39	lbs.
Water per pound of coal from and at 212 degrees,	8.76	lbs.
Water per pound of combustible from and at 212 degrees,	9.48	lbs.

The test on boiler No. 68 is interesting on account of the grade of coal employed, this being bituminous coal from mines in the region of Pittsburgh, Pa. The boiler is not one from which to expect an economical result, since it is small in size and deficient in heating surface. The rate of combustion is somewhat low, but in spite of this the temperature of the escaping gases is excessive, as would be expected. The result of this test is similar to that obtained on boiler No. 61, using a similar kind of fuel, though less favorable, for the reasons named.

Boiler No. 69.

Kind of boiler,	Plain cylinder.
Number used,	One.
Horse-power (basis 10 square feet),	Thirty-nine.
Age,	Several years.

Dimensions.

Diameter of shells, three in number,	30	in.
Length of shells,	30	ft.
Area of heating surface,	394	sq. ft.
Area of grate surface,	36.1	sq. ft.
Area through flue,	5.4	sq. ft.
Height of chimney,	120	ft.
Width of air spaces and metal bars in grates,	1-2	in.
Distance of grate to shell,	17	in.
Distance of flat bridge to shell,	4	in.
Ratio of heating surface to grate surface,	10.9	to 1
Ratio of grate surface to flue area,	6.6	to 1
Kind of brick setting,	Common.	

Results of Tests.

		Test No. 130.	Test No. 131.	Test No. 132.
Kind of coal,		Bituminous Cumberland.	Bituminous Cumberland.	Anthracite, Chestnut No. 2.
Condition of fire at start and stop,		Thin fire.	Banked fire.	Ordinary, with preliminary heating.
Kind of run,		Ordinary.	Ordinary.	Continuous.
Duration,	hrs.	9.5	12.2	5.2
Coal consumed dry (including wood equivalent),	lbs.	2,579	3,338	2,014
Percentage of ash,	%	10	10.3	19.3
Water evaporated,	lbs.	17,270	22,119	9,643
Coal per hour,	lbs.	271.4	272.5	383.6
Coal per hour per sq. ft. of grate,	lbs.	7.5	7.5	10.6
Water per hour,	lbs.	1,817.9	1,805.6	1,836.6
Water per hour per square foot of heating surface,	lbs.	4.6	4.6	4.7
Horse-power developed,	H. P.	61.9	60.8	62
Boiler pressure,	lbs.	81	80	83
Temperature of feed-water,	deg.	78	90	90
Temperature of escaping gases,	deg.	Melts zinc.	–	–
Draught suction,	in.	0.18	0.17	0.16
Water per pound of coal,	lbs.	6.70	6.63	4.94
Water per pound of coal from and at 212 degrees,	lbs.	7.86	7.70	5.75
Water per pound of combustible from and at 212 degrees,	lbs.	8.74	8.59	7.03

Boiler No. 69 is of the ordinary type of plain cylinder boiler, the peculiarity of which is the small area of heating surface which it contains. The tests on this boiler show a very low grade of economy. Test No. 132 may be compared to test No. 89, made on a similar boiler with similar coal. This test gave a much poorer result than test No. 89, which is evidently due to the higher rate of combustion and the increased quantity of waste heat in the escaping gases, which occurred in this case. The principal interest in these tests is the comparative results obtained on the tests with Cumberland coal, during one of which the fire was banked for some ten hours. The loss produced by banking appears from these results to be quite small, the percentage of difference being only 2 per cent.

Between test No. 130 and test No. 132 there is a difference of about 20 per cent. in the evaporation per pound of coal, that is, between the results obtained with Cumberland and anthracite chestnut No. 2.

Boiler No. 70.

Kind of boilers,	Galloway.
Number used,	Six.
Horse-power (collective, makers' rating),	One thousand, four hundred and forty.
Kind of coal,	George's Creek Cumberland.
Age,	Three months.

Dimensions.

Diameter of each shell,	84	in.
Length of shell,	28	ft.
Area of heating surface,	5,628	sq. ft.
Area of grate surface,	217.6	sq. ft.
Area through flue,	60	sq. ft.
Width of air spaces and metal bars in grates,	Air 1 in., metal 3-8 in.	
Height of chimney,	230	ft.
Ratio of heating surface to grate surface,	25.9	to 1
Ratio of grate surface to flue area,	3.6	to 1

Results of Test.

	Test No. 133.	
Manner of start and stop,	Running with thin fire.	
Kind of run,	Continuous.	
Duration,	12.7	hrs.
Coal consumed dry,	47,638	lbs.
Percentage of ash,	4.1	%
Water evaporated,	370,448	lbs.
Coal per hour,	3,756.9	lbs.
Coal per hour per square foot of grate,	17.3	lbs.
Water per hour,	29,210.3	lbs.
Water per hour per square foot of heating surface,	5.2	lbs.
Horse-power developed,	1,024.3	H.P
Boiler pressure,	51.2	lbs.
Temperature of feed-water,	36.7	deg.
Temperature of escaping gases,	533	deg.
Draught suction,	0.64	in.
Percentage of moisture in steam,	7	%
Water per pound of coal,	7.78	lbs.
Water per pound of coal from and at 212 degrees,	9.40	lbs
Water per pound of combustible from and at 212 degrees,	9.80	lbs.

Boiler No. 70 is an internally fired boiler, having two furnaces in each shell. The heating surface consists largely of vertical tubes of a conical shape, which extend from top to bottom of a large flue which passes from the furnaces to the end of the boiler. The products of combustion pass forward through this flue and backward beneath the shell, entering the chimney flue at the front end.

The test on this boiler shows the effect upon the economy produced by a high rate of combustion and a small extent of heating surface. The temperature of the escaping gases is excessive, and the evaporation per pound of coal is much below that obtained where these unfavorable conditions do not exist.

A test of one of these boilers, made under exceptional conditions, a special fireman being employed for the purpose, gave an evaporation of 11.06 pounds of water from and at 212 degrees per pound of combustible, the steam being dry. The rate of combustion was 22.4 pounds of coal per square foot of grate per hour, and the temperature of the escaping gases 575 degrees.

Boiler No. 71.

Kind of boiler,	Water-tube.
Number used,	One.
Horse-power (basis 12 square feet),	One hundred and thirty-six.
Kind of coal,	Bituminous, Cambria.
Age,	Eight years.

Dimensions.

Number of tubes 4 inches outside diameter,	80	
Length of tubes,	18	ft.
Area of heating surface,	1,638	sq. ft.
Area of grate surface,	36	sq. ft.
Width of air spaces and metal bars in grates,	3-4	in.
Ratio of heating surface to grate surface,	45.5	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No. 134.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	10.6	hrs.
Coal consumed dry (including wood equivalent),	6,185	lbs.
Percentage of ash,	10.5	%
Water evaporated,	52,206	lbs.
Coal per hour,	608.9	lbs.
Coal per hour per square foot of grate,	16.89	lbs.
Water per hour,	4,946	lbs.
Water per hour per square foot of heating surface,	3	lbs.
Horse-power developed,	166.3	H. P.
Boiler pressure,	62.4	lbs.
Temperature of feed-water,	88.3	deg.
Temperature of escaping gases,	471	deg.
Draught suction,	0.2	in.
Percentage of moisture in steam,	0.42	%
Water per pound of coal,	8.44	lbs.
Water per pound of coal from and at 212 degrees,	9.78	lbs.
Water per pound of combustible from and at 212 degrees,	10.93	lbs.

NOTE. — The coal when fired contained 3.7 per cent. of moisture.

The test on boiler No. 71 is of general interest, showing the performance of a water-tube boiler. In this case the cleaning of the outside of the tubes had been neglected, in the course of the ordinary work of the boiler, though they were blown off with a steam jet preparatory to the test. The heating surface, although of ample area, was doubtless for this reason somewhat inefficient, and this was evidently the cause of the somewhat large amount of waste heat in the escaping gases, and for the comparatively low economic result.

Judging by the high percentage of ash, the coal was inferior in quality to the best grade of bituminous coal.

BOILER NO. 72.

Kind of boilers,	Cast-iron sectional.
Number used,	Two.
Horse-power (collective, basis 12 square feet),	One hundred and forty.
Kind of coal,	Bituminous, Cambria.
Age,	Fifteen years.

Dimensions.

Area of water-heating surface,	1,687	sq. ft.
Area of steam-heating surface,	562	sq. ft.
Area of grate surface,	69.7	sq. ft.
Width of air spaces and metal bars in grates,	1-2	in.
Ratio of water-heating surface to grate surface,	24.2	to 1
Ratio of steam-heating surface to grate surface,	8	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No. 135.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	10.4	hrs.
Coal consumed dry (including wood equivalent),	6,580	lbs.
Percentage of ash,	12.4	%
Water evaporated,	48,059	lbs.
Coal per hour,	660.2	lbs.
Coal per hour per square foot of grate,	9.47	lbs.
Water per hour,	4,641.9	lbs.
Water per hour per square foot of water-heating surface,	2.8	lbs.
Horse-power developed,	155.2	H. P.
Boiler pressure,	54.7	lbs.
Temperature of feed-water,	92.6	deg.
Temperature of escaping gases,	462	deg.
Number of degrees of superheating,	29	deg.
Draught suction,	0.09	in.
Water per pound of coal,	7.30	lbs.
Water per pound of coal from and at 212 degrees,	8.41	lbs.
Water per pound of combustible from and at 212 degrees,	9.61	lbs.

NOTE. — The coal when fired contained 3.7 per cent. of moisture.

The test on boiler No. 72 shows the performance of a sectional boiler which had been used many years and which had probably become inefficient, on account of deposits of scale upon the interior surfaces. The economic result is low, although this is offset to some extent by the superheated condition of the steam. The temperature of the escaping gases is high, a further indication of the inefficiency of the surface.

Boiler No. 73.

Kind of boilers,	Vertical tubular (fire-box).
Number used,	Two.
Horse-power (collective, basis 13 sq. ft.),	Two hundred and sixty.
Kind of coal,	George's Creek Cumberland.
Age,	Sixteen months.

Dimensions.

Diameter of shell,	60	in.
Height between heads and length of tubes,	15	ft.
Number of tubes (collective) 2½ inches outside diameter,	360	
Diameter of fire-box and grate,	6	ft.
Distance of grate to lower tube sheet,	3	ft. 6 in.
Width of air spaces and metal bars in grates,	Air 1-2 in., metal 5-8 in.	
Area of water-heating surface,	2,521	sq. ft.
Area of steam-heating surface,	880	sq. ft.
Area of total heating surface,	3,401	sq. ft.
Area of grate surface,	56.7	sq. ft.
Area through tubes,	8	sq. ft.
Ratio of water-heating surface to grate surface,	44.5	to 1
Ratio of steam-heating surface to grate surface,	15.7	to 1
Ratio of total heating surface to grate surface,	60.2	to 1
Ratio of grate surface to tube area,	7.1	to 1

Results of Test.

	Test No. 136.	
Manner of start and stop,	Thin fire.	
Kind of run,	Ordinary.	
Duration,	10.3	hrs.
Coal consumed dry (including wood equivalent),	7,588	lbs.
Percentage of ash,	7.7	%
Water evaporated,	81,730	lbs.
Coal per hour,	739.3	lbs.
Coal per hour per square foot of grate,	13.08	lbs.
Water per hour,	7,962.8	lbs.
Water per hour per square foot of water-heating surface,	3.2	lbs.
Horse-power developed,	243.1	H. P.
Boiler pressure,	46.4	lbs.
Temperature of feed-water,	186	deg.
Temperature of escaping gases,	427	deg.
Number of degrees of superheating,	18	deg.
Draught suction,	0.28	in.
Water per pound of coal,	10.77	lbs.
Water per pound of coal from and at 212 degrees,	11.34	lbs.
Water per pound of combustible from and at 212 degrees,	12.29	lbs.

Boiler No. 73 differs from other vertical boilers referred to in the paper, being provided with a fire-box and an ample area of heating surface. There is no brick-work about the setting, excepting the brick ash-pit which supports the boiler. The outside of the shell is protected by a covering of asbestos board and hair felting. The interior surfaces in the boiler were known to be reasonably clean.

The conditions both in the matter of boiler proportions and the character of the work done during the test are favorable to economy. The proportion of water-heating surface to grate surface is as large as good practice in horizontal boilers requires; there is a considerable amount of steam-heating surface; there is a minimum chance for external radiation; there are no avenues for the entrance of air except those provided in the fire-door; and during the test the rate of coal consumption was sufficient to secure excellent combustion. These conditions are favorable to economy and it is seen that the result of the test bears out the expectations which the conditions justify.

The result is higher than any in the paper thus far reported. The figure which comes the nearest is that obtained on boiler No. 47, which is of the same type, though more complicated in its construction. Boiler No. 47 gave the same evaporation per pound of combustible, but the steam in that case was saturated, while in this case it is superheated 18 degrees.

Boiler No. 74.

Kind of boiler,	Horizontal return tubular.
Number used,	One.
Horse-power (basis 12 square feet),	One hundred and five.
Kind of coal,	George's Creek Cumberland.
Age,	Several years.

Dimensions.

Diameter of shell,	60	in.
Length between heads and length of tubes,	17	ft.
Number of tubes 3½ inches outside diameter,	76	
Area of heating surface,	1,262	sq. ft.
Area of grate surface,	23.7	sq. ft.
Area through tubes,	4.4	sq. ft.

Width of air spaces and metal bars in grates,	Air 1-2 in., metal 3-8 in.
Distance of grate to shell,	24 in.
Distance of flat bridge to shell,	9 in.
Character of space behind bridge,	Open (see memorandum).
Ratio of heating surface to grate surface,	53.1 to 1
Ratio of grate surface to tube area,	5.4 to 1
Kind of brick setting,	Air supplied at bridge. (See memorandum.)

Results of Test.

	Test No. 137.
Manner of start and stop,	Ordinary, with preliminary heating.
Kind of run,	Continuous.
Duration,	9.7 hrs.
Coal per hour,	3,149 lbs.
Percentage of ash,	7.5 %
Water evaporated,	34,116 lbs.
Coal per hour,	323 lbs.
Coal per hour per square foot of grate,	13.6 lbs.
Water per hour,	3,499.4 lbs.
Water per hour per square foot of heating surface,	2.8 lbs.
Horse-power developed,	108.1 H. P.
Boiler pressure,	61.7 lbs.
Temperature of feed-water,	178.7 deg.
Temperature of escaping gases,	413 deg.
Draught suction,	0.15 in.
Water per pound of coal,	10.83 lbs.
Water per pound of coal from and at 212 degrees,	11.54 lbs.
Water per pound of combustible from and at 212 degrees,	12.47 lbs.

Boiler No. 74 is of the common horizontal tubular type, though it has somewhat unusual proportions. These are secured by the provision of a small area of grate surface. The boiler is of unusual length and has tubes of larger diameter than most of the boilers of the paper. The boiler is supplied with air at the bridge wall in a different manner from that followed in any other case. The arrangement is such that the air enters in two currents, one above and one below the burning gases. One supply comes from the bridge wall, which is hollow, and it is discharged through perforations in the rear face of the wall near the top. The other current is supplied

first to a second hollow wall placed a short distance behind the bridge wall, and suspended, so to speak, from the shell of the boiler, thereby causing the products of combustion to pass beneath it. The air emerges through perforations in the front face of this wall near the bottom.

The economic result of the test is the highest of any given in the paper for this type of boiler. It is to be noted that the rate of combustion is high, and the temperature of the escaping gases is comparatively low. These are two conditions which are favorable to a good result. The effect of air supplied at the bridge wall has been beneficial in numerous cases where bituminous coal is used. It should be specially beneficial in this case, for the reason that the arrangement by which it is admitted provides for a very thorough mixture with the products of combustion.

Preliminary to the beginning of this test the boiler was heated and steam was raised to its working point, and there was no pause in the production of steam from beginning to end. It may be held that this furnishes a reason for the excellent performance over many other boilers in which there was no preliminary heating beyond the ordinary conditions, and in which the noonday interval occurred. Some improvement may be attributed to this cause, but its extent is believed to be trifling.

The character of the combustion, as seen through a peek hole at the back end of the boiler, was excellent, and a notably high degree of heat was produced. There was a marked absence of dense black smoke discharged from the chimney.

BOILER No. 75.

Kind of boilers, ...	Water-tube.
Number used, ...	Two.
Horse-power (collective, basis 12 sq. ft.),	Two hundred and sixty.
Kind of coal, ...	Pea and Dust one part, Powelton Bituminous four parts.
Age, ...	New.

Dimensions.

Number of tubes 4 inches outside diameter,	144	
Length of tubes,	18	ft.
Area of heating surface,	3,126	sq. ft.
Area of grate surface,	70	sq. ft.
Area through flue,	11.1	sq. ft.
Height of chimney,	80	ft.
Width of air spaces and metal bars in grates,	Air 3-8 in., metal 5-8 in.	
Ratio of heating surface to grate surface,	44.7	to 1
Ratio of grate surface to flue area,	6.3	to 1
Kind of brick setting,	Passages in walls supplying air to sides of furnace.	

Results of Test.

	Test No. 136.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	11.6	hrs.
Coal consumed dry (including wood equivalent),	13,644	lbs.
Percentage of ash,	9.0	%
Water evaporated,	133,096	lbs.
Coal per hour,	1,176.2	lbs.
Coal per hour per square foot of grate,	16.7	lbs.
Water per hour,	11,441.6	lbs.
Water per hour per square foot of heating surface,	3.7	lbs.
Horse-power developed,	403.3	H. P.
Boiler pressure,	77	lbs.
Temperature of feed-water,	38	deg.
Temperature of escaping gases,	402	deg.
Draught suction,	0.5	in.
Water per pound of coal,	9.75	lbs.
Water per pound of coal from and at 212 degrees,	11.86	lbs.
Water per pound of combustible from and at 212 degrees,	13.01	lbs.

NOTE. — The coal when fired contained 4.5 per cent. of moisture.

The test on boiler No. 75 is remarkable on account of the high character of the result. It is superior to any given in the whole series of tests. That economy ought to be secured is evident when the conditions under which the boiler worked are examined. There is a high ratio of heating surface to grate surface. As a consequence, a large share of the heat is absorbed, the temperature of the flue gases being at the com-

paratively low figure of 402 degrees. A high rate of combustion prevails, and this feature is one which tends to economy. Air is admitted at the bridge wall to enhance the combustion of the gases, a provision which, with bituminous coal, as various tests given in the paper show, increases the efficiency. Added to all is the fact of the new and presumably clean condition of the surfaces.

Boiler No. 76.

Kind of boilers,	Water-tube.
Number used,	Two.
Horse-power (collective, basis 12 sq. ft.),	One hundred and fifty-seven.
Kind of coal,	George's Creek Cumberland.
Age,	Four years.

Dimensions.

Number of tubes 4 inches outside diameter,	96	
Length of tubes,	16	ft.
Area of heating surface,	1,886	sq. ft.
Area of grate surface,	38.9	sq. ft.
Area through flue,	9.2	sq. ft.
Width of air spaces and metal bars in grates,	Air 5-8 in., metal 3-8 in.	
Ratio of heating surface to grate surface,	48.4 to 1	
Ratio of grate surface to flue area,	4.2 to 1	
Kind of brick setting,	Common.	

Results of Test.

	Test No. 139.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	10.7	hrs.
Coal consumed dry (including wood equivalent),	6,812	lbs.
Percentage of ash,	6.4	%
Water evaporated,	59,113	lbs.
Coal per hour,	634.9	lbs.
Coal per hour per square foot of grate,	16.3	lbs.
Water per hour,	5,510.6	lbs.
Water per hour per square foot of heating surface,	2.9	lbs.
Horse-power developed,	189.3	H. P.
Boiler pressure,	72.9	lbs.
Temperature of feed-water,	66	deg.
Temperature of escaping gases,	523	deg.
Draught suction,	0.21	in.
Percentage of moisture in steam,	0.4	%

	Test No. 129.
Water per pound of coal, ...	8.68 lbs.
Water per pound of coal from and at 212 degrees, . .	10.28 lbs.
Water per pound of combustible from and at 212 degrees,	10.98 lbs.

Preparatory to the test on boiler No. 76 the cracks in the brick-work and all the crevices around the doors, with which the boiler is provided for purposes of cleaning, were filled with fire-clay. The effect of reducing by this means the quantity of air which was drawn in, was revealed by means of the draught gauge. With no fire in the furnace, and the fire and ash doors closed, a draught of 0.31 of an inch in the main flue, with wide-open damper, produced a draught of 0.25 of an inch between the damper and the boiler, before the openings were closed, and the full draught of 0.31 of an inch after they were closed. When the damper was in a partly closed position, the draught in the main flue remaining the same, the amount realized was 0.09 of an inch before stopping up the openings, and 0.20 of an inch after stopping them up. The crevices were not fully closed, else the full draught would have been realized when the damper was partially open. Repeated tests, made beforehand with open crevices, showed a lower economic result than that given here, and this proves that the leakage of too much air into a furnace produces no beneficial effect upon the economy.

The result of the test is inferior to that corresponding to highest economy, and it is evident that it is due largely to the high temperature of the escaping gases. Comparing the result with that obtained from boiler No. 75, it is seen that a higher proportion of heating surface exists, and the rate of combustion is about the same, while the temperature of the gases is higher to the extent of 121 degrees. The heating surface appears to have been inefficient. It is known that the interior surfaces were clean. The exterior surfaces were as clean as a steam jet could make them, but it is surmised that after the considerable period of service to which they had been subjected, under the use of bituminous coal, they may have been covered with a non-conducting deposit which failed to be removed by the steam.

Boiler No. 77.

Kind of boilers,	Water-tube.
Number used,	Two.
Horse-power (collective, basis 12 sq. ft.),	Four hundred and thirty.
Kind of coal,	Cumberland.
Age,	Two years.

Dimensions.

Number of tubes 4 inches outside diameter,	252	
Length of tubes,	17.7	ft.
Area of heating surface,	5,150	sq. ft.
Area of grate surface,	102	sq. ft.
Area through flue,	18	sq. ft.
Width of air spaces and metal bars in grates,	Air 3-8 in., metal 1-2 in.	
Ratio of heating surface to grate surface,	50.5	to 1
Ratio of grate surface to flue area,	6.1	to 1
Kind of brick setting,	Common.	

Results of Test.

	Test No. 140.	
Manner of start and stop and kind of run,	Ordinary.	
Duration,	10.96	hrs.
Coal consumed dry (including wood equivalent),	13,420	lbs.
Percentage of ash,	6.3	%
Water evaporated,	125,336	lbs.
Coal per hour,	1,224.4	lbs.
Coal per hour per square foot of grate,	12	lbs.
Water per hour,	11,437.8	lbs.
Water per hour per square foot of heating surface,	2.2	lbs.
Horse-power developed,	357.2	H. P.
Boiler pressure,	83	lbs.
Temperature of feed-water,	173.6	deg.
Temperature of escaping gases,	* 398	deg.
Percentage of moisture in steam,	0.7	%
Water per pound of coal,	9.34	lbs.
Water per pound of coal from and at 212 degrees,	10.05	lbs.
Water per pound of combustible from and at 212 degrees,	10.73	lbs.

Note — The coal when fired contained 2.7 per cent. of moisture.

* Owing to leakage of air into the flue through an idle boiler, which was set close to the two in use, and through openings around the dampers, this temperature is doubtless below the real temperature of the escaping gases.

Boiler No. 77 calls for no special comment. It is of large size and well proportioned, but it failed to give a high economic result. Comparing it with boiler No. 75, and assuming that the conditions which existed there are those necessary for the best work, it would seem that the low result is produced by a low rate of combustion, attended by an excessive amount of waste heat. The waste heat, which for the reasons given in the foot note is not shown to its full extent by the indication of the thermometer, points to inefficiency of the heating surface, such as would be produced by incrustation or by a deposit on the exterior of the tubes.

The PRESIDENT. Gentlemen have heard the paper, and if anybody has anything to say about it or any question to ask, now is the time.

Mr. MANNING. Mr. President and Gentlemen: I think we are all very much indebted to Mr. BARRUS for this paper on boilers, as it is certainly the best and most reliable information open to us on the subject. At the same time, I cannot let it go by without taking issue with Mr. Barrus on one or two points.

In the first place, where he speaks of superheated steam, he would rather lead me to the idea that it would be a good plan to superheat steam two or three hundred degrees. Theoretically there is a slight gain there, but practically it would be death to the engines. Where steam is to be carried a long distance, it is undoubtedly good economy to superheat to a considerable degree; but where it is used in the engine, a superheat of from twenty to thirty degrees above the temperature due to the pressure, I think, is about all that there can be any economy in. That prevents, in large part, the initial condensation, and it is merely making the same amount of water the vehicle for a greater amount of heat. To get this superheated steam, I give the preference to a vertical boiler. I think that Mr. Barrus's comparison between a horizontal and a vertical boiler is hardly a fair one. That is, he acknowledges himself that, with two exceptions, the vertical boilers were of bad design; that they were deficient in heating surface. They even fell below the horizontal boilers in that respect; whereas, they should be made, and can be made, without any trouble, to far exceed a horizontal boiler in the ratio of heating surface to grate surface. That enables a boiler to have a high furnace temperature, which is undoubted economy, and at the same time deliver the gases lower. Now, the test of boiler No. 73 he throws out of his comparison between horizontal and vertical boilers, because the gases were higher; but, notwithstanding the fact of the escaping gases being higher, the test shows the highest efficiency of any vertical boiler tested. The reason for the gases being higher is that there was no inleakage of air. In nine

cases out of ten there is an inleakage, with horizontal boilers, of from 10 to 15 per cent. of the volume passing up through the chimney, which has never been through the boiler. That, of course, reduces the temperature of the gases; whereas, the reduction of temperature, instead of being economy, is a dead loss; because the heat has gone through the boiler and then been diluted afterwards, thus impairing its efficiency. Of course, the higher the chimney temperature the better draught you obtain. By lowering that temperature after the gases have been through the boiler you interfere with it.

I have no doubt in my mind that a vertical boiler, properly designed, with a large ratio, say of fifty-five to sixty-five square feet of heating surface to one of grate, enables you to burn a high rate of fuel to the square foot of grate surface, because you are able to control the temperature of the steam so that you can always get it superheated to any degree you desire, and still secure a high degree of efficiency.

Now as to the length of the tests made by Mr. Barrus. They are good for comparison as long as they are all made by the same man; but tests of this length made by different men, under different circumstances, are no good basis for comparison. A boiler test, to be of much value as an engineering fact, must be one of at least thirty-six hours, and better, seventy-two hours, in duration, continuously, without any night intermissions or day intermissions; but, as that is not practicable, the results that he has given us are the very best under the circumstances. I think we are all very much indebted to Mr. Barrus.

The President. Are there any other remarks upon this subject?

A Member. I would like to ask Mr. Manning if he has made any tests of the boilers under his charge that will show better results than are shown by Mr. Barrus, if he is willing to tell us?

Mr. Manning. I have made tests that show a little better than Mr. Barrus'. They were made on a boiler that had not been used twenty-four hours before it was used for the test. The test was a continuous one, for thirty or thirty-six hours,

I am not certain which. The result of the test showed 13.1 pounds of water per pound of combustible, from and at 212 degrees. I do not think that a boiler is apt to keep up to that for its lifetime. The boilers that Mr. Barrus tested, I think, had been in use some eighteen months, and showed a decidedly higher temperature of escaping gases — as I should expect they would — than the boiler which I tested. The boiler which I tested being perfectly clear and clean, the surfaces cleaned inside and out, and giving a better absorption of heat, I got better results. The test of capacity, also, gave very nearly as good results.

A MEMBER. I would like to inquire if that was a vertical boiler, and if so, the size of the tubes?

Mr. MANNING. Yes; it was a vertical boiler that I had reference to. The diameter of the tubes was two and one-half inches. There is another fact that Mr. Barrus touched on, which is, that the area of tube opening must have a certain relation to the grate surface. Therefore, to get a certain amount of heating surface, it must be obtained by lengthening the tube. In other words, both in horizontal and vertical boilers, the thing turns almost entirely on the relation of the length to the diameter of the tubes, and not on the length of the boiler. If we exceed thirty diameters in length of tube its efficiency decreases very rapidly, until at ninety diameters there is almost no efficiency whatever.

The PRESIDENT. If no further discussion of this subject is desired, the meeting is open for any matter that the members care to bring up.

A MEMBER. I would like to ask Mr. Barrus if he will answer this question: Supposing I want to put in a new steam boiler, would he recommend a vertical boiler or a horizontal boiler, and also the diameter and the length of the different tubes which are put into these different boilers? After all his experiments and tests, I should think he would be able to give us an answer to the inquiry, What boiler would be economical to put in for the best plant?

Mr. Barrus. I would state that I have recently recommended vertical tubular boilers in preference to any other, for several plants, with tubes two and a half inches in diameter. These were of the general dimensions given for boiler No. 73 of the paper.

I would like to say, in reply to what Mr. Manning brought up, that I did not intend to advocate in this paper a high degree of superheating, but simply to state the fact as to what superheating would do. As I stated, in ten tests on different engines, where the steam was superheated an average of thirty degrees, there was a gain of 5 per cent. I do not say that superheating to 228 degrees would be desirable, but I simply state that as a fact.

A Member. I would like to ask Mr. Manning if, in the expensive steam plant he has had built at the Amoskeag, he put in anything but vertical boilers?

Mr. Manning. No, sir; we are using nothing but vertical boilers. There are, of course, places where certain circumstances make a horizontal boiler advisable; but, all other things being equal, for efficiency, economy, power to force it, safety, and almost every other reason, I prefer a vertical boiler to a horizontal. In a vertical boiler, as the water drops down, the coldest part of the tubes is exposed. In a horizontal boiler, with loss of water, the very first thing to come out is the hottest tube. That is, the upper row of tubes is always hotter, and considerably hotter, than any other row. With a vertical boiler and tubes fifteen feet long, the water can drop, with one hundred pounds of steam on, within two feet of the lower tubes and not injure the boiler.

A Member. I would like to ask Mr. Barrus what system he used in his test of oil. He says his highest test shows fifteen pounds of water for a pound of oil. I understand they are doing a good deal better than that per pound of oil.

Mr. Barrus. I used a burner which embraced a steam jet which vaporized the oil and injected it into the furnace, and the flame which it produced played upon a mass of rock in the

furnace. There was nothing peculiar about it; just an ordinary plain burner.

A MEMBER. If it is in order to make a suggestion to the Executive Committee, I would like to call their attention to a new method of cooking which is being developed by Mr. Atkinson, with a view to their considering whether it might not be worth while to ask him to present it to our Association. It is rather a departure from the ordinary subjects of a manufacturers' meeting, but it has an important bearing upon the cost of living.

The PRESIDENT. No doubt the Executive Committee will be glad to consider the suggestion.

Mr. WALTER E. PARKER. The papers presented to the Association to-day are all from non-members. MR. REED'S paper was prepared with much care and accuracy, after a thorough investigation of the methods employed in picking cotton, and is a valuable contribution. The paper from Mr. BARRUS, it seems to me, is the most valuable on that subject — possibly with one exception — ever presented to this Association; and I move that the thanks of this Association be extended to the persons who have favored us to-day.

This motion was seconded and carried unanimously.

The PRESIDENT. The gentlemen will please accept the thanks of the Association. I may be allowed to add my personal thanks to Mr. BARRUS for his paper. I agree perfectly with what Mr. PARKER has said. I think it will be found to be a paper of great value to all the steam users in the Association.

A MEMBER. I would like to ask Mr. Manning, for the information of some who do not know, what distance his boilers are from his engines?

Mr. MANNING. The nearest pair of engines, a pair of thirty-six by six feet Corliss engines, running sixty-two revolutions, are about seven hundred feet from the boilers. The next engines are some five hundred feet further than that, on the upper level. One pair of thirty by six feet Corliss engines,

running forty-nine revolutions, developing about twelve hundred horse-power at their full power, and another engine of about a thousand horse-power, stand about twelve hundred feet from the boiler-house, by the most direct route.

The PRESIDENT. If there is no further business, a motion to adjourn will be in order.

On motion, the meeting then adjourned.

[No. 46.]

N. E. COTTON MANUFACTURERS' ASSOCIATION.

PROCEEDINGS

OF THE

TWENTY-FOURTH ANNUAL MEETING,

HELD AT BOSTON,

APRIL 24, 1889.

PRECEDED BY

CATALOGUE OF MEMBERS.

BOSTON:
WRIGHT & POTTER PRINTING COMPANY,
18 POST OFFICE SQUARE.
1889.

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Total number of Honorary Members 2
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CALL FOR MEETING.

BOSTON, April 1, 1889.

DEAR SIR: — The stated annual meeting of the Association will be held at the Massachusetts Institute of Technology, Boylston Street, Boston, on Wednesday, April 24, 1889, at 10 o'clock A.M., for the choice of officers for the ensuing year, and the transaction of any other business which may properly come before it.

After the business of the meeting is concluded, by invitation of the board of government, papers will be read by the following-named gentlemen, upon the topics stated: —

Mr. W. S. KELLEY of Lowell, Mass., on the APPLICATION OF ELECTROMOTIVE POWER TO MILL WORK.

Mr. EUGENE N. FOSS of Boston, Mass., on the STURTEVANT SYSTEM OF HEATING, VENTILATING AND MOISTENING TEXTILE MANUFACTORIES.

Mr. CHARLES F. TARBELL of Boston, Mass., on the BARNARD SYSTEM OF STEAM HEATING AND DRYING.

Other speakers have been invited to discuss the above topics.

The papers to be read will be printed in advance of the meeting, and a copy of either supplied to any member who shall apply for it to the secretary.

By vote of the board of government,

AMBROSE EASTMAN,

Secretary.

PROCEEDINGS.

Pursuant to the foregoing notice, the stated annual meeting of the NEW ENGLAND COTTON MANUFACTURERS' ASSOCIATION was held at the Massachusetts Institute of Technology, Boston, on Wednesday, April 24, 1889, at 10 o'clock A.M.

In the absence of the president, Vice-President PARKER occupied the chair, and called the meeting to order.

The secretary read the call for the meeting.

On motion, it was voted that a committee of five be appointed by the chair to nominate officers for the ensuing year. The chairman appointed the following as such committee: WILLIAM S. WHITNEY of Fall River; JEREMIAH CLARK of Lowell; FRANKLIN NOURSE of Saco, Maine; JOHN H. HIGGINS of Slatersville, R. I.; and HERBERT FISHER of Taunton.

The reports of the secretary, the treasurer and the auditor were then read, and, by vote of the Association, were accepted and ordered to be placed on file.

The secretary read the names of persons nominated for membership, who were recommended by the board of government for election. The list is as follows: —

Messrs.	ARTHUR H. GULLIVER, .	Grosvenor Dale, Conn.
	FRANK HARRIS, . .	Woonsocket, R. I.
	WALTER B. KNIGHT, .	Bozrahville, Conn.
	CHARLES H. RICHARDSON, .	Lowell, Mass.
	SAMUEL J. THOMPSON, .	Valatie, N. Y.
	HENRY M. WILCOX, . .	Millbury, Mass.

They were unanimously elected.

[illegible] the following list

[illegible] McArthur.
[illegible] S. S. Spencer,
[illegible] R. Smith.

[illegible] may be authorized to
[illegible]. The ballot was cast
[illegible] declared the officers above

[illegible] in order upon the pro-
[illegible] by Mr. W. S. Kelley of
[illegible] of Electro-motive Power

[illegible] preparation of this paper, care has
[illegible] technical terms as possible; so that,
[illegible] of view, the treatment is exceedingly
[illegible] As I proceed, if there are any persons who
[illegible] ask questions upon special points, I wish they
[illegible] upon the copies which they have, and pre-
[illegible] the reading is concluded. It is a subject not
[illegible] understood, and I wish to make it as clear as pos-
[illegible]

[illegible] then read his paper, illustrating it by reference
[illegible] large diagrams hung upon the wall, and by an
[illegible] motor attached to a shaft in such a manner as to com-
[illegible] functions of a motor and dynamometer, — this appli-
[illegible] of electric motors having been designed by Mr. Kelley
[illegible] special reference to mill work.

APPLICATION OF ELECTRO-MOTIVE POWER TO MILL WORK.

By W. S. KELLEY, Lowell, Mass.

The transmission and distribution of power is one of the chief problems engaging the attention of the mechanical and mill engineer; and, as the object sought in the use of electricity in power service is to provide a more safe, satisfactory and economical solution of the problem, a consideration of electro-motive power, in its more general aspects, may not be out of place, to preface in a measure the consideration of special applications, which it is the object of this paper to bring to the attention of the members of this Association.

Strictly speaking, the transmission and distribution of power cannot in all cases be disassociated entirely, so as to be considered apart. There may be transmission without distribution, as when power is carried a considerable distance, and expended as a single unit; but distribution without transmission is impossible, for each unit into which the power is subdivided must be transmitted to the point where expended. As, in the interest of clearness, a distinction is desirable, transmission will be employed in its restricted meaning, and all local transmission included in distribution.

Under the conditions which obtain in textile manufacturing, and the limitations of heretofore known methods of transmission, it has not been largely employed; although, when there are many buildings distributed over several acres of ground, obtaining power from a central source, transmission becomes an important item. It will play a more important part in man-

ufacturing operations as electrical transmission becomes better known.

Electrical power transmission, and electro-motive power, are terms of comparatively recent origin; and, with their introduction, it is desirable to indicate as clearly as possible just what they signify.

Electricity is not as yet a primal source of energy. There has not yet been discovered any free source of electricity; as, in the case of heat stored in coal, gravity in falling water, energy of motion in air, etc., it is a created form, in the same sense as steam.

If we want to use it, we must make it by the expenditure of power obtained from some other source; and the cost of this source, less the greater economy obtained by employing it in this form, is the cost of electro-motive power.

Power recovered from gravity by a water-wheel, or from heat by an engine, appears as the energy of motion; it is only portable over a limited area by mechanical means. Power in the form of electric energy is easily portable, — is in its *most* portable form; and energy of motion is transformed into electric energy, simply to carry it to some other point, where it can be expended more economically or under more favorable conditions.

Electricity, as employed in power service, is simply an agent of transmission and distribution, — a convenient, tractable, yet powerful means of carrying and distributing energy of motion. Electrical transmission, then, is simply the employment of electricity to transmit power from the point where best obtained to the point where best expended.

Electro-motive power is the energy of motion, recovered from electric energy by the electric motor. The only significance of the term is to show that electricity was the agent of transmission; the power recovered does not differ in quality from the initial power; from beginning to end of the system it is the same, but appears at different points under different forms: first, as energy of motion; second, as electric energy; third, as energy of motion again.

Let me repeat, electricity is not primal energy, but a derived form, — one more convenient for transmitting and distributing power obtained, from whatever source. Respecting far transmission, it may be said that the transmission of large units of power considerable distances is no longer a visionary scheme, but an accomplished fact, a practical and commercial success; not in one instance only, but in numbers of them, in this country and abroad.

A practical demonstration of the possibilities of electrical power transmission is found in the experiments of Deprez, in 1882, between Munich and Meisbach, a distance of thirty-seven miles, in which a metallic circuit of seventy-four miles was employed; and between Paris and Creil, in 1885, a distance of thirty-four miles, employing a metallic circuit of sixty-eight miles. Switzerland furnishes several commercial examples, in one of which fifty horse-power is being transmitted five miles, with an efficiency of seventy per cent. One of the most notable examples of far transmission was installed by the Sprague Company on the Feather River in California, in which fourteen motors were operated at different points for mining operations in the river bed, on a circuit of eighteen miles.

In the city of Boston is to be found an excellent example of power transmission in the four hundred horse-power developed by electric motors scattered all over the city, and supplied from the Edison incandescent station at Head Place. Every electric street railway is an illustration of the far transmission of power; and these are being installed so rapidly that they will soon cease to be novelties. One of the very first was the Portrush Electric Railway in Ireland, having its extreme end five and one-half miles from the power station, the power being developed by two Yankee turbines.

There is no more occasion for a manufacturer to become an electrician to decide upon any case of electrical transmission than that he should become a hydraulic engineer to put in water power. There is no occasion to be sceptical, or to speculate as to what can be done in any given case; for responsible

companies stand ready to tell you just what can be accomplished under any given conditions, and, if feasible, to estimate cost and guarantee results.

There are two ways in which the ability to economically transmit power by electricity for several miles will be of vast importance and utility to manufacturing interests in New England: first, by allowing mills already in operation to re-enforce their power by some unimproved water privilege in the vicinity; and second, by rendering the location of new mills entirely independent of the power plant.

Upon the water power of New England was the prosperity of her industries founded. Electrical power transmission will give them a new impetus, for it will make more water power available, thus rendering it more than ever a successful competitor of steam. Water power is portable only in a very limited sense, and then only at the expense of a very heavy capital outlay for canals; their care and maintenance is also no inconsiderable item. The location of such canals is not a matter of choice; and their location, determined by land level and character, has fixed the location of the mills. Except for the single question of power, the location might be exceedingly undesirable; it might be unhealthy; it might necessitate great expense for substructures; it might be inconvenient for freights, necessitating an always present expense for trucking. All these adverse conditions may be, and have been, encountered in the same instance; but there was no alternative. The power question was paramount to everything else; the mill must be placed where the power was, and the enterprise loaded with all the adverse conditions, or the power could not be made available.

In the close competition of the present day, such encumbrances to any location are almost prohibitive; they would preclude the construction of the water-power system of Lowell, and possibly of Manchester and Lawrence. In electrical transmission we have a means of using the power, and avoiding the drawbacks incident to its locality. Formerly it was, take it with all adverse conditions, or leave it; now we can take the power and leave the conditions.

strictly, are coupled the vastly superior facilities afforded by electricity over other methods, in the distribution and economical use of power, as developed later in treating of a special application, some idea can be formed of the tremendous influence which such a system is bound to exert upon all classes of manufacturing industry.

With present methods, it is immaterial whether our initial power is the energy of motion from an engine or water-wheel; one is confined in using it to the point where developed, or to a fixed, rigid system of distribution, losing rapidly in efficiency as the system is extended. With electrical transmission, on the other hand, one has simply to lengthen or multiply conductors, to carry the power to a distant point or to as many points as desired, without loss of efficiency. Given one hundred horse-power of electrical energy, and it can be carried one hundred feet or one thousand feet, expended at one point or at a hundred different points, grouped together or widely separated, without loss of efficiency; thus showing, in its ability to satisfy all conditions of power transmission, subdivision and distribution, a flexibility and economy which no other system can hope to approach.

Some eminent authorities hold that no system of transmitted energy can be made commercially successful, unless the cost of the power at the far end shall be less than would have to be paid for its production there, by the most available means. This, on the face of it, seems exceedingly plausible, to almost have the force of an axiom; but it will bear inspection, for it ignores subdivision and distribution. If we restrict the system to transmission simply, and for a moderate power, to be employed in one or two units at the far end,— leaving distribution out of the question entirely, — the statement will be substantially correct. But, under the conditions which obtain in mill work, — a large aggregate power distributed over a considerable area in many small units, — the statement is no longer correct; for the flexibility of the system as developed in this paper, and the special advantages which inhere of convenience, economy of power, of operation, of

maintenance, etc., which no mechanical system of distribution can hope to equal, will in themselves offset a considerably greater initial cost. This is a principle well understood and appreciated in cotton manufacturing; it justifies greater initial cost of machinery that will save operating expenses, and the expenditure of fifteen hundred dollars to two thousand dollars to dispense with a laborer.

With the means of transmission heretofore available, the conditions which govern the expenditure of power in textile manufacturing has made the transmission of any considerable amount of power more than a few hundred feet impracticable. The location of the power determined the location of the mill; and, with established plants, interest will centre largely in the application of electricity to the distribution of power. It here comes into direct competition with the complex mechanical methods included under the general term gearing, comprising shafts, couplings, pulleys, belts, ropes and gears for straight transmission, and bevel gears, quarter-turn belts, etc., for angular transmission.

It is here, in the remarkable facilities afforded for the subdivision and distribution of power, that its great advantage in power service is most apparent; and, when coupled with far transmission, its advantages are so manifest that it is rapidly superseding other methods. They may be efficient under certain conditions for transmission; but, where it becomes necessary to subdivide the power and distribute it in innumerable small units, they utterly fail; recourse must be had to the mechanical means just mentioned, at the point where subdivision becomes necessary. Hydraulic, pneumatic and steam transmission can be subdivided to a limited extent, but at great expense and loss of efficiency, — so great, that, when electricity is available, they are now almost out of the question.

They lose efficiency rapidly by subdivision and by every angle turned; the pipes necessary are cumbersome, must be given a fixed position, and allowed to remain undisturbed. They are constantly in need of attention and repairs, and are influenced injuriously by changes of temperature. With elec-

tricity this is all changed; subdivision of conductors involves no loss of efficiency, and but slight expense; they can be taken round corners with equal facility as in a straight line; the conductors are small and flexible, and may be changed to other positions without detriment to themselves or the service while transmitting their maximum power; there is nothing to explode, break or give way, and extremes of temperature have no effect. Its special adaptability to the subdivision and distribution of power will go a great way toward making far transmission an object, wherever natural sources of power are available. To what extent it will supersede the present mechanical methods for simply distributing power, when the factory contains the power plant, the conditions which govern any particular line of manufacturing in any locality must determine; depending largely upon the aggregate power, and the units into which it is subdivided.

Although shafting has been displaced entirely in a number of factories and workshops here and abroad, and a motor employed to drive each individual machine, the policy cannot be generally considered advisable under present conditions; particularly where the machinery is so compactly placed, and represents so small units of power as in cotton mills. The capital outlay required in such a case is yet a serious consideration. Each motor would take some room; a small motor would need as much care as a large one, and be much less efficient as a converter of energy. The advantages of electrical distribution are obvious, and, up to a certain point, unquestioned; but, like everything else, it has its limiting conditions; and these are such, that, in cotton mills, light shafting for distributing electro-motive units to individual machines is, to a certain extent, a desirable auxiliary. Exact relations will be considered later, in a particular case.

Essential Parts of the System.

The essentials of any system of electrical transmission are: (*a*) some source of power, as water-wheel or engine; (*b*) a dynamo for converting the energy of mechanical motion

into electric energy; (*c*) a conductor (usually a copper wire), which shall form a complete metallic circuit between the two terminals of the dynamo, to provide a path for the electricity to traverse; and (*d*) a motor introduced into this circuit, to reconvert the electric energy passing through it into mechanical motion.

Strictly speaking, the current of electricity, so called, is not directly the product of the dynamo, but a result of its action. In the production of electro-motive power, the dynamo performs precisely the same office that is performed by the sun in the production of water power. The sun raises part of a body of water to a higher level; offer it a free path back again, and the water rushes down, turning water-wheels in its descent.

The dynamo creates a difference of potential (difference of level) pressure, between two points, — terminals; provide a metallic conductor, — a path between the two points, — and the electricity rushes from the higher to the lower point, from the + to the — pole. Allow this current of electricity to flow through a motor, and it will turn it, — mechanical motion is recovered.

To carry the parallel still farther: Where there is a small stream with high head, one can use the whole volume of water in one wheel; farther down the same water can be made to turn another wheel, and so on, till the whole fall of the stream is utilized. With an electric current of high potential, the whole of it goes through a motor, coming out with reduced potential (at a lower level); the next motor reduces it still farther, and so on, till the whole potential is utilized. This is the "constant-current" method, obtaining electro-motive power, employed on the high-tension or "arc circuit," and necessitates a mechanical governor on the motor. Again, where there is a large volume of water, a canal is dug parallel to the stream; at various points water is allowed to flow from the canal into the river through a water-wheel; all the wheels operate under the same head of water, but only a portion of the whole volume goes through each wheel. With the "constant-potential" method of employing electro-motive power, there is a large volume of

electricity of low potential (head); motors are placed at intervals on span wires, between a wire representing the level of the canal, and another the level of the river; each motor uses but a portion of the electricity, but all operate under the same potential. With this method of using electricity, which is that employed by the Sprague Company, perfectly automatic regulation is possible, without mechanical means. The advantage in using a stream of electricity instead of a stream of water, is, that we can have our fall anywhere we choose, and as much or little fall as we choose.

The electric motor is not, as is popularly supposed, a machine of recent invention. Both dynamo and motor are the perfected results of seventy years of scientific research, of experiment and invention. The genesis of the electric motor is found in the experiment of the Danish scientist, Oersted, in 1819, by which he demonstrated the relation between electricity and magnetism, and showed for the first time that energy in the form of electricity could be converted into energy in the form of mechanical motion. It was but a short step to the discovery of the electro-magnet, one quickly taken, and the door swung open upon the era of electricity at work, — the one in which we live.

The enormous attractive force exerted by an electro-magnet upon soft iron operated with scarcely less effect upon inventors; and, between 1830 and 1860, the number of motors invented for converting this force into motive power was legion. Among the best known of the early inventors may be mentioned Henry, Davenport and Page, in this country; Jacobi, in Russia; Sturgeon and Little, in England; and Davidson, in Scotland. In 1834 Jacobi constructed a motor which propelled a boat on the Neva, containing fourteen persons, at the rate of three miles an hour. Professor Page invented an electric engine which attracted wide-spread attention. Assisted by an appropriation of thirty thousand dollars by Congress, he constructed an electric locomotive in 1851, which actually hauled a train of cars from Washington to Bladensburg, a distance of five miles, at the rate of nineteen miles an hour. But, as batteries were

cumbersome, of great annoyance, and as a source of power fifty times as expensive as steam, commercial success was an impossible attainment for these early inventors. It was only after the discovery of the dynamic principle almost simultaneously by Siemens, Wheatstone, Hjorth and Varley, in 1867, that electro-motive power or electrical power transmission became commercially possible.

The principles which govern the action of dynamo and motor are identically the same. The converse of the principle which converts energy of motion into electric energy, allows, when the operation is reversed, of converting electric energy into mechanical motion; although, owing to the different conditions under which dynamos and motors operate, various differences in design and details of construction have been found desirable. Generally speaking, any continuous-current dynamo can be used as a motor, and any motor as a generator of electricity.

Industrial necessities, rather than scientific discoveries, determine the actual progress in the application of new principles to practical results. Thus, although the vital principle of electro-mechanics, — reversibility, the ability of a dynamo to convert power applied to it into electricity, or electricity applied to it into power, — the realization of which implies the electrical transmission of power, was enunciated by Dr. Pacinotti of Pisa in 1860, and accepted by most scientists, it was not actually demonstrated by practical use until employed in an exigency, as a possible way out of a tight place, at the Vienna Exposition in 1873.

In one exhibit were two Gramme dynamos, which were to be used to illustrate this very principle of reversibility; one was to be driven by power to produce electricity; the other was to be used as a motor for running a pump, the current being obtained from a primary or storage battery, both of which had been provided. The Exposition was to be formally opened by the Emperor at ten o'clock A.M., on the third day of June. The sun set on the second, and Monsieur Fontaine, who had the exhibition in charge, failed to get the motor into action, from either the primary or storage battery. He says: "This

was a great disappointment, especially as it prevented my showing the reversibility of the Gramme dynamo. It puzzled me the whole of the evening and ensuing night, to find a means to accomplish my object; and it was only on the morning of the third day of June, a few hours before the exhibition was to be opened, that the idea struck me to work the small machine by a derived circuit from the large one."

The second machine started off as by magic, driving the pump at such a rate as to throw the water way beyond the reservoir. To overcome this, he reduced the current by introducing a considerable length of cable. "The total length of cable in circuit," he continues, "was over two kilometers (three miles), and this great length gave me the idea, that, by means of two Gramme machines, it would be possible to transmit mechanical energy over long distances."

It required a decade to popularize this idea sufficiently to secure its commercial employment; but it resulted in placing a new and powerful lever in the hands of modern engineering, with which to lift the industries of the world onto a plane of greater productiveness. Electrical power transmission, and consequently heavy electrical engineering, date from Monsieur Fontaine's experiment. Although the electric motor was of much older origin, it may be said that this event first made possible its industrial success. Time was required for the perfection of mechanical details, and even up to the time of the electrical exhibition in Paris, in 1881, dynamos and motors bore rather the character of scientific apparatus than substantial mechanical appliances. The principles of their operation were, however, well established; and later improvements have been mainly improved design, better and more substantial mechanical construction; so that to-day, as converters of energy, it is hard to conceive of anything more perfect or more simple, both in principle and construction.

Electricity is not produced by friction in a dynamo, nor is power obtained from an electric motor by reason of the attraction of a magnet for iron.

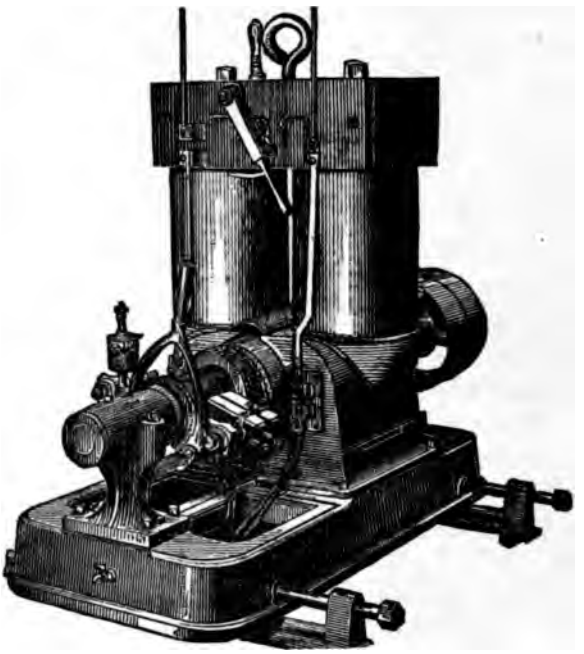
The principle governing the action of both is the reciprocal

influence manifested between magnetism and electricity under certain mechanical conditions. Revolve a conductor in the field (space between the poles) of a magnet, and electricity is produced in the conductor; place a conductor, through which a current of electricity is passing, in the field of a magnet, and the conductor will revolve. The essentials for obtaining these results are: the electro-magnets, which are usually stationary; the armature placed so as to revolve between the poles of the magnets; and the commutator and brushes, the office of these being twofold, — to transfer electricity from the coils of wire revolving with the armature, and to produce a continuous flow of electricity (current) in one direction in the outside circuit. What could be more simple than the construction which this principle allows? Take, for example, a loop of wire bent in the form of a rectangle, supported by a spindle along its longest axis, between the poles of a permanent magnet; bring the ends of the wire directly to and along opposite sides of a small wooden cylinder on the spindle, and support strips of copper against opposite sides of this cylinder. Rotate the spindle, and, as the loop of wire cuts through the magnetism emanating from the poles of the magnet, electricity will be developed in the wire; connect the two strips of copper bearing against the cylinder with a wire, and a current of electricity will flow through it, — this is a generator.

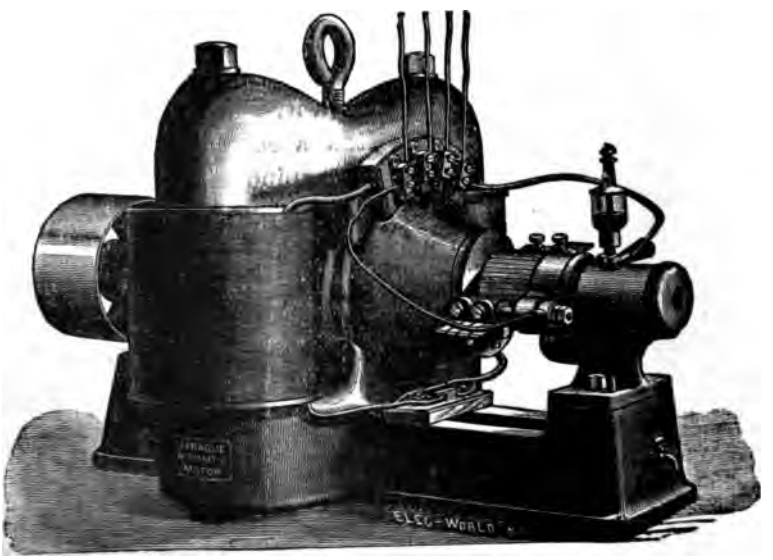
With the spindle at rest, allow a current of electricity to flow through the loop of wire; the spindle immediately begins to rotate, — this is a motor.

Substitute for the permanent magnet powerful electro-magnets, multiply the number of loops of wire along the spindle, and, according to size, relation of parts and character of construction, the machine will represent ten, fifty or one hundred horse-power, as the case may be. [Parts of motor shown by diagram.]

No machine has ever been invented, nor does it require a prophet to predict that none ever will be, capable of creating energy. To obtain something from nothing mechanically is an impossibility, a never-to-be-hoped-for attainment. But energy



Dynamo for Generating Current.



Sprague Standard Stationary Motor.

of one sort can be transformed into energy of another sort; into a kind available for use as motive power. This is the office of all prime movers. To get electro-motive power, the motor must be fed with electricity, which represents power from some other source; to get the electricity, one must expend power to drive a dynamo; whether it be power developed by an engine, a water-wheel, or a windmill, is immaterial.

Power is energy harnessed for work, and, under the same conditions of direction and regulation, is the same, and can be used with like effect, whether the impelling force is wind, water, steam or electricity.

Electro-motive power yields to no other form in availability; in direction it is rotary, and its regulation can be made as near perfect as is the case with any prime mover. Except the two bearings of the armature spindle, — there being no other part in motion, — the only point for wear in a motor is between the commutator and brushes.

With these, improvement in material and in methods of manufacture is rapidly bringing them to such a state of perfection that the wear will be entirely uniform and hardly appreciable. This attained, the electric motor will require almost no attention, will be mechanically almost indestructible, and in all respects prove an ideal prime mover.

Compared with a steam engine, their efficiency — *i. e.*, the ratio of useful effect delivered by pulley — is about as 5 to 1.

A 25 horse-power Sprague automatic motor will convert 95 per cent. of the energy of the electric current led into it into useful effect; while 18 per cent. of the heat energy of steam converted into useful effect is a good performance for a steam engine.

With the exception of the smaller machines, all first-class dynamos and motors have an efficiency of 90 per cent. and over. Eighty-seven and a half per cent. of the power applied to dynamo has actually been developed by a motor for work when transmitting 50 horse-power. Eighty-five per cent. may be looked for in practice with the best types of machines, where the motor units are not less than 25 horse-power. The loss

here stated is the combined loss of the double conversion by dynamo and motor, with the two machines side by side; when separated by placing the motor on a different floor, in a different building, or a mile distant, the loss in transmission over the circuit from dynamo to motor and back must be added. This may be anywhere from 5 per cent. to 15 per cent. or more, as we choose to make it. For instance, 100 horse-power developed by a water-wheel is to be transmitted one mile: 15 per cent. is allowed for the double conversion by dynamo and motors; with 5 per cent. lost in transmission, 80 per cent., or 80 horse-power, will be recovered at the far end for work; with 15 per cent. lost in transmission, only 70 per per cent., or 70 horse-power, will be recovered. Will the extra expense for copper necessary to reduce this loss to 5 per cent. be warranted by the 10 horse-power gained?

With a tension of about 500 volts, the cost of copper for a loss of 5 per cent. would be about $5,000; for a loss of 15 per cent., about $1,700; difference, $3,300, or the value of 10 horse-power, for a little over three years, at a rental of $100 per annum, neglecting interest. This question is one that will be determined largely by value of power, and whether there is an abundance or scarcity at the source. Another factor is the additional cost of dynamos for power lost; smaller per cent. loss means smaller dynamo equipment. The passage of a current of electricity along a conductor is at the expense of friction, depending upon tension and size of conductor; this friction is manifest as heat, and the heat developed in the conductor is proportional to the power lost in transmission. Aside from its representing loss of power, the heat also reduces the conductivity of the wire. For ordinary distances, 7 per cent. to 10 per cent. affords a satisfactory and economical service. Carefully insulated copper wire is usually employed as conductor, as it combines conductivity, cheapness and strength in a greater degree than any other.

In practice it is seldom found desirable to use a wire larger than No. $\frac{4\text{-}0}{0000}$; this is .46 inch diameter Brown & Sharpe gauge. The power that such a wire will transmit depends on the dis-

tance, the potential, and the loss allowed. With a potential of 500 volts and a loss of 7 per cent., this wire would deliver 35 horse-power about 5,000 feet distant; half that power, 10,000 feet. Allowing a loss of 12 per cent., it will deliver nearly 63 horse-power 5,000 feet distant. This means that a greater power can be forced over the wire if a greater proportional loss is allowed. In the first case, the actual loss on the wire would be nearly 10 horse-power; in the second, more than 21 horse-power.

Distance in electrical transmission is merely a relative term. Theoretically, there is no limit to the distance; practically and commercially, it is limited by two factors having a mutually inverse relation to each other, — the electrical tension or potential, and the cost of copper.

The weight and consequently the cost of copper conductors varies inversely as the square of the potential. Hence, if the weight of copper necessary to transmit 500 horse-power one mile, at a potential of 500 volts, with a given per cent. loss, costs $5,000, one could, by doubling the potential, employing a current of 1,000 volts, reduce the weight of copper three-fourths, and consequently the cost to $2,500. In any given case, to double the power transmitted, other conditions remaining the same, means an equal additional investment for copper.

If the weight of copper per horse-power is fixed at which electrical transmission will be commercially successful, with a given loss in transmission, the distance over which the power can be transmitted will vary directly as the potential; therefore, if it is feasible to transmit power 5 miles economically under 500 volts pressure, the same power can be carried 10 miles without increasing the cost for copper, by doubling the potential, making it 1,000 volts, or 20 miles, by making it 2,000 volts.

But, to double the distance and change no other conditions would call for four times the weight of copper; *i. e.*, for the same potential, the weight of copper to transmit a given power with a given loss varies as the square of the distance.

Thus, with a given potential, the cost of copper becomes

prohibitive when a certain distance is reached; and various considerations limit the potential that may be employed, among which may be mentioned the difficulty, electrically and mechanically, of handling and controlling high tensions, and the danger to life and also from fire, from imperfect insulation. So far as present knowledge goes, the wire suffers no deterioration in power transmission; once in place, it will never need replacing by new. The cost of erecting the line will be measurably proportional to the distance, and, within certain limits, to the power of the line with any given tension; whether overhead or underground conductors are used, is a matter of choice with low potentials. An underground line will cost from two to three times as much as a pole line.

The cost of dynamos and motors in large units is in large measure independent of distance and potential, varying as the power and loss in transmission. It is variously estimated from $85 to $100 per horse-power.

Application to Mill Work.

Turning now from the general consideration of the principles involved and the demonstrable facts relating to electrical transmission, to the point of this paper, — some practical application of electro-motive power in mill work, — the question at once encountered is, How, and in what ways, will its application to mill work prove an industrial and commercial success? These will be considered topically, as follows: —

First. It will make available, at points where mills will prove remunerative, sources of power unsuitably located for building or manufacturing. This in a general way has been quite fully treated already.

Second. It can, in addition to such use, displace all mechanical means of transmission between engine or water-wheel, and the shafts which distribute power to machinery and to individual machines even, with the attendant advantages of a flexible power system, and greater economy in the expenditure of power.

Third. It can be made useful as an auxiliary portable

power for local and temporary use, anywhere about the mill, in doors or out.

Fourth. It is able to provide unexcelled transportation facilities.

Second. — Flexibility and Economy of Systems.

The engineering problem presented by the conditions of textile manufacturing is to subdivide the power from sources near or remote into a large number of small units, and distribute them for application over a considerable area, on one or more floors.

Once the available power is in the form of electricity, the distribution is merely a question — a very simple one — of introducing a sufficient number of wires of the proper size. A great and immediate advantage is obtained in not having to provide for any mechanical motion; no force or movement is ever apparent to the eye, as with shafts, belts, ropes, gears, etc. The conductor is clean, cool, does not move, and appears entirely inert. It can be bent, moved, or shifted to another place, while transmitting its maximum power. It can be brought round sharp corners, and, having little weight, can be readily fixed in position. Thus no obstacle is presented in taking power into rooms and places awkwardly situated for mechanical transmission. There is no noise, heat, dirt, or odor, nor anything to explode or give way. Properly insulated, the conductor offers no danger to person or property, and ensures the lowest rates of insurance.

The same circuit that furnishes 100 horse-power can as conveniently be tapped for 1 horse-power. Whatever difficulty presented, would be in the application of the power units to the work. Will the conditions which obtain in cotton-mill practice, which govern arrangement of machinery, etc., be acceptably fulfilled in the application of electro-motive power? To test this question, plans of a mill designed to be equipped throughout with electro-motive power were recently prepared at the Lowell Machine Shop, under my personal supervision. They afford a most complete and satisfactory answer to this

question. The organization of the mill was for a ten-hour daily production of 7,700 pounds of 36-inch cloth, four yards to the pound, 56 picks per inch and 56 threads per inch of sley, 21's average number. [Plans shown.]

The plans, as completed, show a building 284 by 76 feet outside, four stories high, with a two-story extension of 34 feet for opening and picking machinery; front and rear towers at centre, the former for entrance and stairways, the latter for elevator, sinks, water-closets, etc. The first and second floors of rear tower afford passage to a two-story structure, 68 by 52 feet, for slashers, drawing-in, cloth room, office, etc.

The upper floor is devoted to carding, drawing, fine and coarse speeders, driven by six independent shafts: three for carding and drawing, each 131 feet long; one for coarse speeders, 63 feet long; two for fine speeders, each 70 feet long. The third floor is occupied solely by the spinning, which is driven by nine independent shafts, each 70 feet long.

The second floor contains spoolers, warpers, slashers, and 300 looms; no shafting except in the extension for picking, where six finishers are driven from one shaft having a motor; and three breakers, each being driven by an independent motor, which also drives the opener on the first floor.

The first floor contains 396 looms in the main mill, with cloth room and office in the rear. In the weave room are seven independent shafts, running the length of the mill, five of which drive 116 looms, — a double row above and below, a single row being driven by the outside lines.

In the cloth room is one shaft 35 feet long, and a short shaft for driving slashers. Outside of the picker room there are but three counter shafts, each 8 feet long, every other shaft to be independently driven by a motor attached to it. The estimate made by the Sprague Company for the entire electrical equipment, including transmission line of 2½ miles, was about $75,000.*

The combined estimates of responsible parties for entire

* Detailed estimates and data covering entire equipment of mill will be found in an article in the December number of the "Textile Manufacturing World."

equipment of shafting, pulleys, hangers, belting, etc., amounted to but $6,860, this being less than 29 cents per spindle with frame filling. Outside of the picker house there is no shaft above $1\frac{15}{16}$ inches diameter; and, excepting three short counter belts 3 inches wide, there is no belting wider than $2\frac{1}{2}$ inches. With these exceptions there are no belts except from shaft to machine.

It has perhaps been noted that no floor space has been reserved for motors. How are they to be placed, and how connected? It would avail nothing for me to urge upon manufacturers the equipment of their mills *throughout* with electro-motive power, if there were no better method available than to place the ordinary stationary motor on the floor, and belt to a shaft. Although an occasional motor thus employed might be used with great advantage, I do not hesitate to affirm that a complète electro-motive equipment of this character would not be satisfactory; and I would not endanger what reputation I may have in this connection by advocating it. But, as representing the Sprague Electric Railway and Motor Company, as well as in my individual capacity, I am able to present to you to-day a method of motor application, with entire confidence not only as to the verdict of the members of this Association, but of practical men in any line of manufacturing; for it is applicable wherever there is a shaft or a machine to drive. It forms part of a complete and comprehensive system for the application of electro-motive power, however large the aggregate, that will not only fulfil every requirement at present imposed, but accomplish much not now possible with any power system; and, in flexibility, in compactness, in facilities afforded for control, for regulation, for economical operation, exceed all other methods of power distribution and application. This system, for the first time publicly presented in this paper, includes electro-motive units of any convenient size; direct flexible connection to shaft or machine; each motor to indicate the power developed at any moment; a continuous record of each motor's service at some central point; and, though as a system forming a connected whole, any one or any number of its

units can be stopped or started without disturbing any other. [Experimental machine exhibited in operation.]

The motor is suspended from, but not supported by, the shaft, and is free to swing to either side, the centre of oscillation being concentric with the centre of the shaft. Pinions on each end of the armature shaft engage spur gears on the line shaft. Normally, the motor hangs perpendicularly in the plane of the shaft. When power is developed, it swings out of the perpendicular, the angle of deflection being proportional to the power developed. The absence of rigid connection between the gears allows of a very gentle start, and relieves them of sudden strains. The power developed is registered by utilizing the swing of the motor. The advantages that result will soon be apparent.

A system for the mill, shown by plans, would include 30 motors for regular service, 28 on as many independent lines of shafting, and one for each of two elevators. These motors range from 5 to 35 horse-power, aggregating 650. To exemplify all the features of electrical power transmission, the mill is supposed to be situated upon a railroad, near where it crosses a stream, half a mile above a considerable fall, at which 600 horse-power is available, and two miles below another, at which 400 horse-power is available. It will be necessary to employ wheels capable of developing nearly 900 horse-power. Now, in this mill, what advantages are afforded by the proposed system of electro-motive power?

(*a*) That of employing water power otherwise unavailable.

(*b*) That of uniting the power from two different points, for expenditure at another.

(*c*) That of avoiding cartage by a location on the railroad.

(*d*) That of choosing a favorable building spot.

(*e*) That of a decreased capital outlay for plant outside of electrical equipment; in support of which may be instanced reduced floor space, by reason of no belt tower, nor space for belts passing from floor to floor. Absence of driving belts and heavy shafting allows a reduction in size, with the simplest and least expensive construction. With ample alleys and spare

floor to handle goods in process, there is in this case but 3.8 square feet per spindle, all told. The saving in capital outlay on hangers, shafting, pulleys and belts is worth reckoning.

(*f*) That of decreased operating expenses. Saving is effected in the care and maintenance of driving belts, belt boxes are avoided, fire risk reduced, and unobstructed floor space allows of a more compact and convenient arrangement of machinery, with its attendant advantages.

(*g*) That of a more economical use of power. It is a peculiarity of electrical transmission, that no power is wasted by reason of a motor being only partially loaded; as the call it makes on the dynamo, and consequently the power transmitted to it, is in exact proportion to the load it carries. It works as economically on partial as on full load; any lessening of the load at once relieves the dynamo, and lessens the duty of the engine or water-wheel driving it.

Facts are the best evidence on this point, and the experience of an industry using electro-motive power entirely will be of interest at this point. The factory runs a 12 × 12 Ball engine, belted direct to an Edison compound wound dynamo, of 50,000 watts capacity at 220 volts; another driving wheel is belted to a counter shaft, from which two lighting dynamos are driven. After expressing complete satisfaction with the results obtained, the account (given at a meeting of mechanical and electrical engineers in New York, February 6) continues: —

"The power which would be required to operate our factory in the usual way, by belting through the floors, was estimated by several engineers, competent in factory construction, to be between 30 and 50 horse-power, without considering the power required for our lights, amounting to an additional 15 horse-power. In other words, we are delivering an estimated 50 to 70 horse-power, and only developing 15 to 30 horse-power, with an average of but 17 to 18 horse-power, for ten hours.

"Whence comes this apparent something for nothing? I will try and explain to you. Every operator in our factory

who has charge of a machine, be it a milling machine or a drill press, a lathe or a planer, has a certain and absolute direct and instantaneous control over the automatic valve gear on our engine in the basement, through the medium of his belt shifter. We will suppose he is using a milling machine; the piece being milled has finished its travel, and the machine is stopped. A horse-power of duty has been taken off the motor driving that machine. Multiply, if you please, the ¼ horse-power hours (supposing it to be stopped 15 minutes each hour) by say 50 machines, running under the same average conditions, and you have a total of 12½ horse-power hours saved each hour. Add this 12½ horse-power to the 18 horse-power, our average load, and we begin to approach the estimated load of our factory under former conditions of practice. To this we should add about 12 or 15 horse-power, which would be necessary to drive a line of heavy main belts through the six floors of our factory; and we have a gross result of 42 to 50 horse-power."

The great economy of this system in the use of power is seen where motors are run from central stations supplying light and power. With 100 horse-power of engine capacity to spare for power, neglecting loss in transmission entirely, 150 horse-power can actually be sold for recovery by small motors. The reason is, that all are not running at the same instant; and, there being no idle shafting to keep in motion, a motor calls for no power when not in operation.

Another reason for economy of power over present methods is, that, with independent lines of shafting, loss of power from poor alignment is reduced; and in this system a motor will instantly feed and register any extra power taken by reason of friction in the bearings; and, thus localized, the remedy is easily and quickly applied. Likewise, any extra power taken by any machine on the line can be immediately detected, and the machine overhauled. The motor is a complete dynamometer for testing power taken by a shaft or machine belted to it, and the mechanical reading can at any time be verified by an electrical test. An additional advantage of having each

shaft independently driven, is, that there need be little idle shafting running. With work ahead or machinery idle for any other reason, the motor can be stopped, and both power and wear saved. But, better still, any one or more motors can be run overtime for operating an elevator, running a line of cards, a slasher, or a section of looms if getting behind, or work done in the repair shop, without running connected lines all through the mill; nothing in operation except at dynamo, and where the work is being done. At all points there is a saving in power. This means less coal to buy and less to handle in a steam plant, and also with water power, where it is hired or where it gets short in summer.

The continuous record of the power developed by each motor for which this system provides makes it the acme of perfection, in the actual basis afforded, for selling and renting power service. The seller is paid for all the power furnished, and the buyer gets the advantage of every possible economy in using it. The record will show the power actually delivered. Such records will as certainly detect and locate incompetency as a watchman's clock. By consulting them, a manufacturer can most effectually oversee both overseers and help. Faithfulness and ability will be as impartially recorded. Such an exact, impartial record, of where, how and by whom the work is being done, will lead to many good results.

In the mill represented, the thirty dials, one representing each motor, will be grouped on the wall in the superintendent's office. A glance will show at once whether any particular motor is stopped or running; if stopped, at what time; if running, how much of the load is on; which elevator is stopped or running; whether orders for stopping or starting certain machinery are promptly executed; and so on. A little consideration will make many advantages apparent. The utility and economy of such a system will be inestimable.

Systematically inspected, this system of electro-motive power can be maintained at a slight expense for attendance and repairs. The motors can be run for long periods without stopping. It is only a question of keeping them clean, oiling

two bearings, and trimming and adjusting the brushes occasionally; all of which can be done as well with the motor in operation as with it stopped. Depreciation of motors is very slight; a very little expense will suffice to keep them in condition indefinitely, if carefully handled. Sprague motors have been operated for years without a dollar's worth of repairs other than a new set of brushes.

When electro-motive power is to be substituted in an existing plant, or employed in a new establishment, the question will arise as to what extent shafting can be advantageously employed. What is the golden mean? This is not difficult to determine. The following general considerations governed the equipment of the mill considered, and will indicate the point to which electrical distribution can now be carried, with undoubted advantage in all cases. Where machinery is scattered, it can be carried even farther, for the assumed condition here is compactly placed machinery.

First. Let it displace every mechanical means for angular transmission. It loses no efficiency in going round a corner; mechanical transmission does. Bevel gears and quarter-turn belts take room, are expensive, are unsightly, require much care, and wear out rapidly; a copper wire is practically everlasting, is inexpensive, takes little room, is hardly noticeable, and requires no care.

Second. Let it displace mechanical means in any case where the question is simply one of transmission. It requires no hangers, no bearings, no oiling, and never gets out of line in such manner as to absorb more power.

Third. With rare exceptions, let it displace all counter belts. Once in place, the conductor is there to stay; never breaks, never slips, never has to be taken up, is always ready to start, and never loses its initial efficiency.

Fourth. Where individual machines require 10 horse-power, or are run intermittently, use a motor for each. Such absorbers of power as idle belts and shafting are thus avoided. It is a peculiarity of electrical transmission, that no power is consumed by, and therefore none transmitted to, motors that

are idle; also, that the actual efficiency in transmission is greater than the theoretical. The size of any wire, and the loss in transmission, is calculated for the maximum load. This is seldom imposed, and partial load means a greater proportional efficiency in transmission. Thus, if 1 horse-power is the calculated loss in transmission with maximum load, there will be but ¼ horse-power approximately lost with half load.

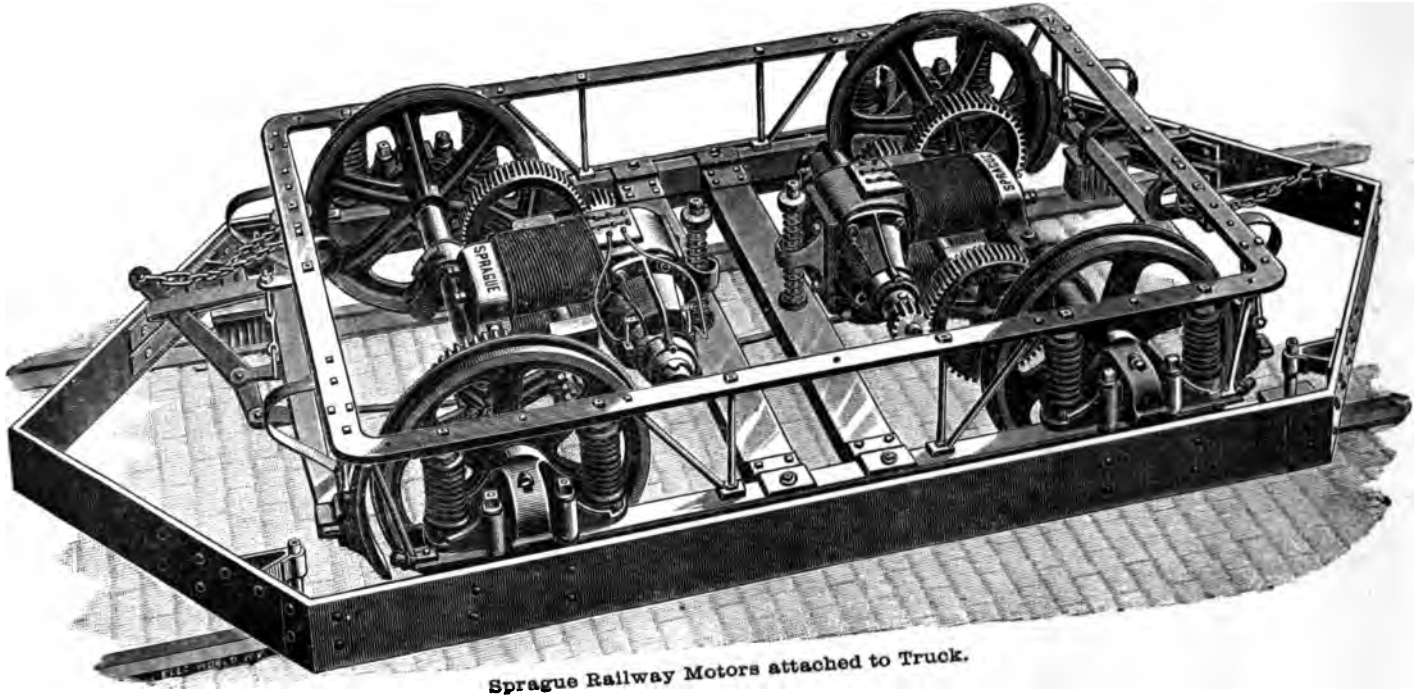
It is not to be supposed that any large establishment will at once substitute electro-motive power in place of present equipment; but almost any mill can make a beginning with no little advantage; for it can be made to displace another by degrees, at an expense for only the amount of power installed at the time.

Take, for instance, a water-wheel inconveniently located, — and I am knowing to several such in different mills, — requiring a complication of shafts, gears and belts for transmission; discard these, belt to a dynamo placed alongside, then lead the current to the most inaccessible and most inconveniently located places in the yard where power is required, with a gain of half as much again in available power.

Once the power is converted into electricity, it can go anywhere with equal facility. Make a beginning by employing electro-motive power in places that require a long transmission, and in top stories. Applied to mules, it would not fail to effect a great economy of power.

Without doubt, any large corporation could effect a saving of at least twenty-five per cent. in the power developed, by substituting electro-motive power. The better one becomes acquainted with the possibilities of electro-motive power, — not what may perhaps be possible in the future, but what is possible to-day, what responsible companies will contract to do and guarantee, — the stronger becomes the conviction that it is bound to displace other methods in power transmission.

Hoisting Crane operated by Sprague Motor.



Sprague Railway Motors attached to Truck.

would be inappreciable. In the case of grades, the extra power is only taken while mounting the grade.

In the case of mill tramways, the Sprague Company is prepared to contract for the equipment all in place ready for operation, or simply to furnish the electrical equipment, and allow purchaser to erect line, build the cars and attach motors, subject to supervision of expert furnished; the work to be guaranteed in either case.

Suspension System.

In some cases there are serious objections or obstructions to the construction of a surface tramway, and in some cases transit is desired between elevated points. To meet such conditions, the Sprague Company has obtained control of the simplest form of electric elevated road known, and is prepared to give estimates for, and to construct, such a line under guaranty as to performance.

This system consists of two stationary steel cables, suspended one about eight feet above the other, supported on a line of posts of either wood or metal, placed, according to load and size of cable, fifty to one hundred and fifty feet apart, and at such an elevation from the ground as not to interfere with surface traffic. The cables are firmly held in position by terminal and intermediate anchorages, and by brackets at the posts. They can be of suitable size to carry a gross weight of from five thousand to six thousand pounds per car. The cables can be made practically indestructible by applying a fixed steel covering or shoe, which takes all the wear and affords the wheels a perfectly smooth surface to run on. This economizes power, lessens running expenses, increases traction, and adds strength to the cables. The cars run on wheels resting on the two cables, the upper carrying most of the weight. The electric current, furnishing the motor with power, passes from the upper cable to the lower through the motor geared to the upper wheels. The cars can be propelled forward or backward, or stopped at any point desired. The cars can be of any pattern, dimensions or material required for the service. They can be run at any speed up to twenty miles an hour.

This system is simple and entirely practical; it is economical to operate and maintain; it is clean, smokeless, cinderless and comparatively noiseless; it is above snow, floods and mud; it avoids dust, landslides and grade crossings; it is free from the danger of surface collisions; it requires no filling, ditching or fencing; in crossing ravines, streams or marshes, no bridge is required; and the service is not impeded by rain, snow or ice.

Its perfect adaptation to mill traffic is such that its use in many localities would cause a large reduction in working expenses. Its value is of the first importance to manufacturers whose success is in saving. It will prove a good investment wherever the traffic will keep it in operation half the time, and in some cases with less.

Freight Handling and Storage.

With both surface and suspension methods for accommodating traffic, I am able to present a more complete and comprehensive system for the storage, handling and delivery of freight for manufacturing corporations located near a railroad than has been available heretofore, — one that will meet all requirements of traffic and local conditions. It combines maximum convenience, facilities and service at minimum cost, and includes (*a*) the storage of all freight — coal, stock, supplies and goods — at the point of delivery, and shipment on the railroad; (*b*) the erection of a storehouse at the end of a spur from the railroad track, with separate fire-proof sections for coal, cotton and goods, an elevator in each section, that for coal being automatic in its action, elevating coal and loading cars without shovelling; (*c*) a railroad track, and tram line from mill running the length of the storehouse in such manner that elevators can receive goods from or deliver to cars on either track; (*d*) the delivery of coal from storehouse to boilers as used; (*e*) the delivery of cotton to picker house as used; (*f*) the delivery of goods from cloth room to and storage at storehouse, and perhaps, to meet certain conditions, the location of cloth room there; (*g*) the use of electro-motive power for tram line, elevators and any other machinery employed.

In the construction of such a storehouse, a sufficient variety in designs would be available to satisfactorily meet all conditions. [Three shown by diagrams.] The tracks could be on the same or different levels, either surface or suspension tram line, as best suited the particular case. The same line might be made to accommodate other local traffic in the mill yard, as the carriage of cloth from weave rooms to cloth room. Such a system would handle the entire traffic of a large corporation with an incredibly small force, and with an expenditure for power that would be hardly appreciable. A coal train with one motor truck and a couple of platform or box cars equipped with motors, and three men, could easily transport one hundred tons in seven hours over half a mile of track, leaving the dynamos free for lighting night and morning. With a level track, there ought not to be an average expenditure of over five horse-power.

Without further elaboration, these applications of electromotive power are laid before this Association as worthy the serious consideration of its members, many of whom are already preparing to test them in practical operation.

The universality which characterizes the possible applications of electro-motive power in industrial affairs is yet hardly appreciated, even by those who are best acquainted with the superior convenience and economy which it offers. Some idea of its universal field, of the undoubted economy with which it can displace existing methods, as well as occupy fields they cannot enter, will doubtless have been gained from what has been advanced in this paper.

The applications considered *are available now* for any who desire to make use of them. Under any given conditions, the Sprague Electric Railway and Motor Company is prepared to say what can be accomplished, to estimate cost and guarantee its work. It is confident that manufacturers will find great advantage in making such applications, and that a careful examination of the merits of the systems it offers can have but one result, — business for it, profit to both.

The PRESIDENT. The paper is before you for discussion.

A MEMBER. Are the cars to which you refer different from those used on the railroad ordinarily?

Mr. KELLEY. With the same gauge of track, any cars may be used. With a narrow-gauge track, standard-gauge cars may be hauled by laying a third rail to make the wide gauge with the outer rail of the narrow gauge, as is done in some cases. If you had occasion to haul ordinary freight cars over a tramway where motor cars were used, one of the motor cars could be used as a locomotive by loading it sufficiently to get the necessary traction.

A MEMBER. In running the mill referred to on page 36, how many men would be required to tend the motors?

Mr. KELLEY. Possibly, two men; I should think more likely, but one; two at the outside would take all the care of the motors that is necessary. They would have to be looked at, say, twice a day, to see that the bearings are kept oiled, and that the brushes are in condition and properly set.

A MEMBER. Would those two men have to be present to start those different motors?

Mr. KELLEY. No, sir. You simply turn a lever to start them. That could be done by the overseer, or by a section hand.

A MEMBER. Do they have to adjust the brushes on the commutators for a change in the load?

Mr. KELLEY. No, sir. The brushes do not require changing for variation in load.

The PRESIDENT. How is the quantity of power developed ascertained in any case?

Mr. KELLEY. It can be tested electrically to get the amount of current. The mechanical indication of power made possible with this motor depends upon the angle it makes with a perpendicular through the shaft, when running with any given load. At rest, it hangs perpendicularly under the shaft; when started, it swings out until a point is reached where it balances the load; there it remains until the load is changed. The heavier the load, the farther it will swing. A finger carried

by the motor traverses a graduated scale, and indicates the horse-power developed at any point. A swing of six inches we will assume indicates two horse-power; ten inches, five horse-power, etc., the distance per horse-power depending on the size of the motor.

Mr. WOODBURY. I would like to inquire if electric motors have been applied to calico-printing machines in this country?

Mr. KELLEY. I don't know; but they can be applied to any machines.

A MEMBER. Is it practicable to store any amount of electrical power? We run our mills ten hours, for instance, and when we shut down there is loss of power from the waste of water. If it were practicable to store electricity, we should get power enough to run additional machinery.

Mr. KELLEY. That may become possible, and many electricians are working to attain that end; but for any considerable equipment I don't think it is practicable at this time, but I think it is quite probable that this point will be reached.

Mr. SHAW. Can you run that machine at any speed you wish?

Mr. KELLEY. They can be made so as to do that, but this is regulated to run at a given speed.

A MEMBER. How much would it cost per mile to transmit one horse-power?

Mr. KELLEY. That is a question impossible to answer in a general way. The equipment of the line varies much with the distance and the tension used. The motors and dynamos for a large equipment entire would probably cost eighty-five dollars to one hundred dollars per horse-power, for motors and dynamos both; but the line would be an additional expense.

A MEMBER. I refer to the line.

Mr. KELLEY. It will depend on the distance, the potential used, and the loss allowed in transmission. With the distance fixed, the other two and consequently the cost can be varied greatly to suit different conditions. If the price per horse-power for copper conductors is fixed at which any case of transmission will be commercially successful, the distance can

be varied (for the same expense) by varying the potential. Again, the power transmitted over any given wire can be varied one hundred per cent. by varying the loss in transmission. A wire that will transmit thirty horse-power one mile, allowing seven per cent. loss, will transmit sixty horse-power if twelve per cent. loss is allowed.

Mr. SHAW. Can you use this motor for driving an elevator? Is there reversible motion?

Mr. KELLEY. It can be applied so as to run in either direction, as in operating street cars, by turning a switch.

Mr. SHAW. You can run an elevator, then, without any belts?

Mr. KELLEY. Yes, sir.

A MEMBER. Can you state what the approximate cost would be to take one hundred horse-power down a stream three miles, where the dam and the wheel are in?

Mr. KELLEY. I should not want to give it off-hand. The cost depends so much upon assumed conditions that general estimates are often misleading. A very little difference in the distance, the potential used and the loss in transmission would vary the result, and these must be settled for each particular case. An estimate in one case is no guide to go by in another. In the case of the mill I mentioned, for six hundred and fifty horse-power, with a transmission of two and a half miles, the whole cost, including motors and line, was seventy-five thousand dollars.

A MEMBER. Have you any practical illustration which you can give as to economy in the use of the electric system? Can you give us the cost per horse-power in any case?

Mr. KELLEY. I can give no better illustration than the one cited in the paper where motors were used. I cannot give the cost for one on any extended scale, but I shall be very glad to furnish figures for any particular case that may be presented to me.

A MEMBER. I am situated like a great many other mill owners, and I would like to get some information on this point. I have mills located so that I have spare power above

and below on the stream; I think I have five hundred horse-power five or six miles above, which I should like to bring down and utilize at the main mill. What I would like to know is, how much it would probably cost to transmit one hundred horse-power, say, from different points, one, two, three or five miles, to a mill. If Mr. Kelley would make such figures, and give them to our secretary, and he will distribute them, we shall be greatly obliged.

Mr. KELLEY. I should be pleased to do that. There is one point in this connection worth mentioning, and that is, that you can transmit five hundred horse-power at a less proportional cost than you can one hundred horse-power. I will prepare an approximate estimate of the cost of transmitting one hundred horse-power one, two and three miles.

A MEMBER. Say for eight miles.

Mr. KELLEY. I would not at present advise the transmission of large powers farther than five or six miles, under ordinary conditions, because you have to use too high a potential, or else lose too much power.

A MEMBER. You instanced a case in which it was transmitted eighteen miles.

Mr. KELLEY. In that case, at Big Bend on the Feather River, they were willing to lose much power on the circuit, and motors were stationed all along the line, which is very different from a straight-away transmission for that distance. You can do it, but you will have to employ a high potential, or use a large amount of copper wire, or else lose immensely in the power transmitted. It is hardly desirable, in an economical point of view, to do so at this time.

A MEMBER. Is it practicable to have intermediate stations, to go to one point, and then start over again?

Mr. KELLEY. It can be done, but I don't think anything can be gained by it. I notice a gentleman present who has a very complete equipment for employing electro-motive power at his mill. He has at one place three wheels geared to a jack-shaft, and a coupling between the first and second, so that he can disconnect one from the others. From a pulley next to the

first wheel a belt drives a clutch pulley on a short counter; from this a dynamo is belted. With the mill running, all that is necessary to start a motor anywhere in the yard, or put on the lights, is to throw in the clutch and start the dynamo. If he wishes to run the repair shop or an elevator in the store-house when the mill is stopped, it is only necessary to uncouple the jack-shaft and start the one water-wheel. He can thus use a motor anywhere without running idle shafting anywhere about the mill.

A MEMBER. Is the system at Big Bend on the Feather River in operation at this time?

Mr. KELLEY. It was discontinued.

A MEMBER. Why?

Mr. KELLEY. Because the gold did not pay to get it out. There was plenty of gold there, but there were too many bowlders to remove to get at it. Electrically, there was no difficulty.

Mr. JEREMIAH CLARK. I would like to say a word in reference to this subject. So far as my observation goes, the arc light current can be used satisfactorily for twenty miles. For the past six months I have been using this current with a Baxter motor of ten horse-power applied to my machine shop and two elevators in my machinery warehouses, each elevator having a capacity of five thousand pounds. I would have preferred the incandescent current, as it is less dangerous, but found it impracticable on account of expense, excepting for short distances. The copper wire necessary for the incandescent current to my place would have cost about two thousand dollars; while, by adopting the arc light current, the common wire, such as used for arc lights, was all that was required for my purposes. The arc light current, being more powerful, has to be handled with greater care; and I have posted a notice as a precaution, also placed a railing around the motor and appointed one man to look after it. I have used it for six months with very good results; it has given me no trouble, and has worked satisfactorily. Since I have had that put in, three other parties have put in the same amount of power each, using the same kind of motor and current. I was in Great Falls, N. H., a short time since, and found at the falls, below

the large mills, considerable water-power to spare; there being only a small woollen mill at this lower fall. The Thomson-Houston Company were putting in two water-wheels to utilize the spare water and furnish power for their system, which they intend to use for lighting and power, carrying it to the village of Great Falls, Dover, Exeter and other places about there, using the arc current for long distances.

Mr. C. J. H. WOODBURY. The speaker has devoted a great deal of attention to showing particular plans for the distribution of power by electricity; and it should be understood that electricity has been successfully applied in many instances for the distribution of power in a manufactory, although I do not recall but one building where it is used entirely, to the exclusion of other methods. That is in Newark, N. J., in an establishment engaged in manufacturing electrical apparatus, where the power is distributed by means of wires contained in a brick flue outside the building, which carries also the steam and water pipes. The motors are not swung on a yoke in the manner represented here, but fastened to the floor, or to shelves projecting from the wall. I have for many years suggested, to mills where electricity is used for lighting, that they should put a motor at the elevator in the store-house, believing that would be a cheaper way of handling the goods, as it would not require independent boilers or long lines of shafting connections, or wire ropes, as is now necessary, as the power would be applied at the spot where it is wanted.

Mr. KELLEY. In reply to a question asked me before, I will say that, if the gentleman will turn to page 33 of my paper, he will find this: "If the weight of copper necessary to transmit five hundred horse-power one mile, at a potential of five hundred volts, with a given per cent. loss, costs five thousand dollars, one could, by doubling the potential, employing a current of one thousand volts, reduce the weight of copper three-fourths, and consequently the cost to twenty-five hundred dollars." Of course, one hundred horse-power transmitted one mile at either potential given would be one-fifth the cost stated; for two miles, multiply the cost for one

mile by four. To erect poles and string the wires one mile for one hundred horse-power would cost two hundred and fifty dollars. Add fifty dollars for every additional hundred horse-power. For dynamos and motors, add one hundred dollars per horse-power. From this, some idea will be obtained of the items of cost in any case of electrical transmission; viz., copper wire, erecting line, dynamos and motors. With a potential of one thousand volts, the cost of wire will equal the cost of dynamos and motors in a transmission of four miles, when the loss is ten per cent. When the loss is fifteen per cent., the two items will about equalize at five miles.

The PRESIDENT. The next paper is by Mr. EUGENE N. Foss of Boston, and is upon the "Sturtevant System of Heating, Ventilating and Moistening Textile Manufactories."

THE STURTEVANT SYSTEM OF HEATING, VENTILATING AND MOISTENING TEXTILE MANUFACTORIES.

By EUGENE N. FOSS, Boston, Mass.

Heretofore, the methods of heating, ventilating and moistening mills have, of necessity, been treated independently. The fact that they are interdependent, and that the complete success of any one is directly dependent upon the other two, has been entirely overlooked. The heating of textile mills, like other manufactories, has resolved itself into simply stringing overhead or about the sides of the building, as the case may be, a given number of feet of pipe calculated by thumb rule. The ventilation has been allowed to take care of itself, no provision being made therefor by the architect, while the heating engineer does not consider that this matter comes within his province. Mill men, in common with other manufacturers, have given little or no attention to the subject of ventilation. The little that has been done in this direction has been from a humanitarian stand-point, and with no thought of any monetary return.

The regulation of the humidity by means of moistening devices has usually been treated as entirely distinct from, and independent of, either the system of heating or ventilating. The perfect system of regulating the humidity depends for its success upon the equal distribution of moisture throughout the mill; and it is evident that this can only be attained through a perfect ventilating system. Likewise, the success of the heating system is co-incident with that of the ventilating; neither can be brought to a perfect condition without the complete adaptation of the one to the other. Only by the merging of these previously independent systems of heating, ventilating

Note. — We are indebted to Mr. W. E. Parker, agent of the Pacific Mills, and Mr. F. P. Sheldon, architect; and to Mr. A. B. Sanford, treasurer, Mr. John A. Sanford, superintendent, and Mr. Wm. T. Henry, architect, of the Globe Yarn Mills, — for information furnished in connection with this paper.

and moistening into one harmonious whole can the desired results be secured. In bringing about these results, nothing is more apparent than the absolute necessity of a positive circulation of the air, in order to secure ample ventilation and a thorough distribution of heat and moisture. For these results, — and that is what we are all looking after, — positive or mechanical means must be employed, and the fan adopted as the accepted agent for impelling air.

It is not the object of this paper to discuss at length the general subjects of heating, ventilating and moistening, but to describe the Sturtevant system, and show wherein it combines in one system the three conditions which must be provided for in every modern textile mill. Briefly stated, the Sturtevant, or blower system, as it is sometimes called, contemplates massing of the steam pipe in coils located in the basement or at some other convenient point, and taking from out of doors the fresh air to be heated, and passing it, by means of a fan or blower, across or through the heating coils, and then distributing it about the building through ducts built into the walls, or through metal pipes provided for the purpose. Thus the necessary supply of pure air, raised to the proper temperature, is constantly furnished to the occupants of the building. The humidity of the air is perfectly regulated by the introduction of a spray of steam or water into the main duct, directly at the mouth of the fan.

In Figs. 1, 2 and 3 is shown the more general type of the combined apparatus, which will serve to illustrate the arrangement. The fan (Fig. 1) is lightly but strongly constructed, and designed for moving large volumes of air at a minimum expenditure of power. The driving power may consist either of a steam engine, direct, connected to the fan shaft, as shown, or of an independent engine, motor or line shaft. The steam coils (Figs. 2 and 3) are made up in a series, consisting of hollow cast-iron bases, into which are screwed staggered rows of vertical pipes, connected by cross pipes at the top. Upon the end of each section is a circular flanged head, divided by a horizontal diaphragm, the upper part communicating with the steam supply, and the lower with the drip. The sides of the

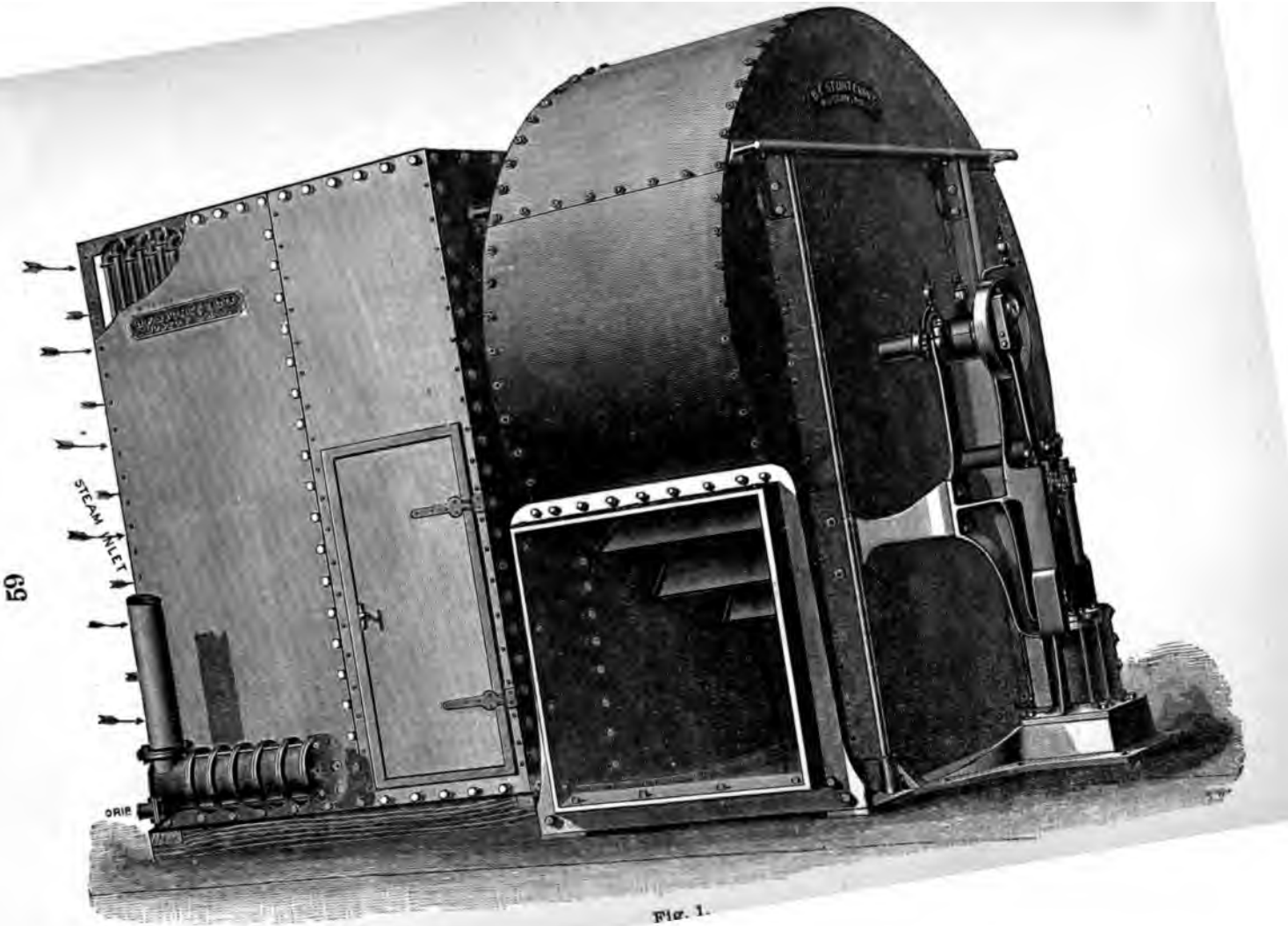


Fig. 1.

Fig. 2.

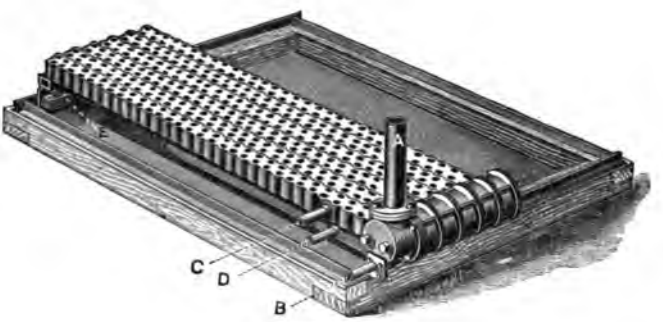


Fig. 3.

heads are planed, and closely fitted, with copper gaskets between; a blank flange placed at one end of the series and the large steam inlet and drip header at the other end. Exhaust or live steam is admitted through the main inlet A (Fig. 3), passes up, over and down through the pipes, and returns to the front of the section through a special passage in the bottom. It is removed as water of condensation at B. C and D represent respectively the exhaust steam inlet and drip for the single independent section provided to utilize the exhaust steam from the fan engine. This section is not in communication with the other sections. The balls E, upon which one end of each section rests, and which allow for expansion, may be seen in both Figs. 2 and 3.

In the investigation of any system or systems of heating, ventilating and moistening, certain important and vital elements must be considered that determine definitely and conclusively the advisability of introduction. The prominent elements that enter into such an investigation are: —

1. First cost.
2. Cost of maintenance.
3. Repairs.
4. Convenience of regulation.
5. Results secured.

Let us look for a moment at the present method of mill heating by direct radiation. Without discussion, the overhead system of steam pipes will be accepted as the most modern and generally adopted. You are all too familiar with the disadvantages of this system, and all have undoubtedly experienced to a greater or lesser degree the annoyances of hammering in steam pipes, the damage resulting from leakage, the necessity of frequently repacking the valves, the constant care and expense of keeping the entire system in order, the frequent inconvenience of properly regulating the system, and the ever-present danger of fire and of freezing, to say nothing of the imperfect distribution of the heat, resulting in the overheating of one portion and the underheating of another, and, above all, of the cost of maintenance. Not, however, until it

is known that as good and even far better results can be secured by eliminating the entire piping system from the rooms, can the actual inconvenience of its presence be fully appreciated.

The Sturtevant system and apparatus, as previously described, locates all the steam pipe in the basement or outside the mill, in a single coil, which brings the steam admission at one point, and under the control of practically a single valve. No pipe whatever is required in the mill, and the attendant disadvantages of hammering, leaking, freezing, repacking of valves, constant repairs, and ever-present fire risk, are entirely done away with.

Again, in massing the steam pipe at a given point, and in using a fan to pass the air over it, a much greater duty is secured from any given number of feet of pipe. The best average condensation in the Sturtevant heater is two and three-tenths pounds per square foot per hour; while, with direct radiation in overhead pipes, it is only three-tenths to four-tenths pounds per square foot per hour. That is, under ordinary conditions, one lineal foot of one-inch pipe, arranged in the form of the Sturtevant heater, will condense, according to the steam pressure, from three to six times as much steam as will be condensed by one lineal foot of one-inch pipe strung around a building in the ordinary manner for direct radiation. In other words, if it requires 50,000 lineal feet of one-inch pipe strung around a mill to heat it by direct radiation, the same mill can, on an average, be heated by 10,000 lineal feet of one-inch pipe arranged in the form of the Sturtevant heater. Contrast the care and repairs on 50,000 feet of pipe, with its attendant valves and connections, with that of one-fifth the amount, put up in the convenient form of the Sturtevant heater; not to speak of other disadvantages attendant upon steam pipe strung around a building.

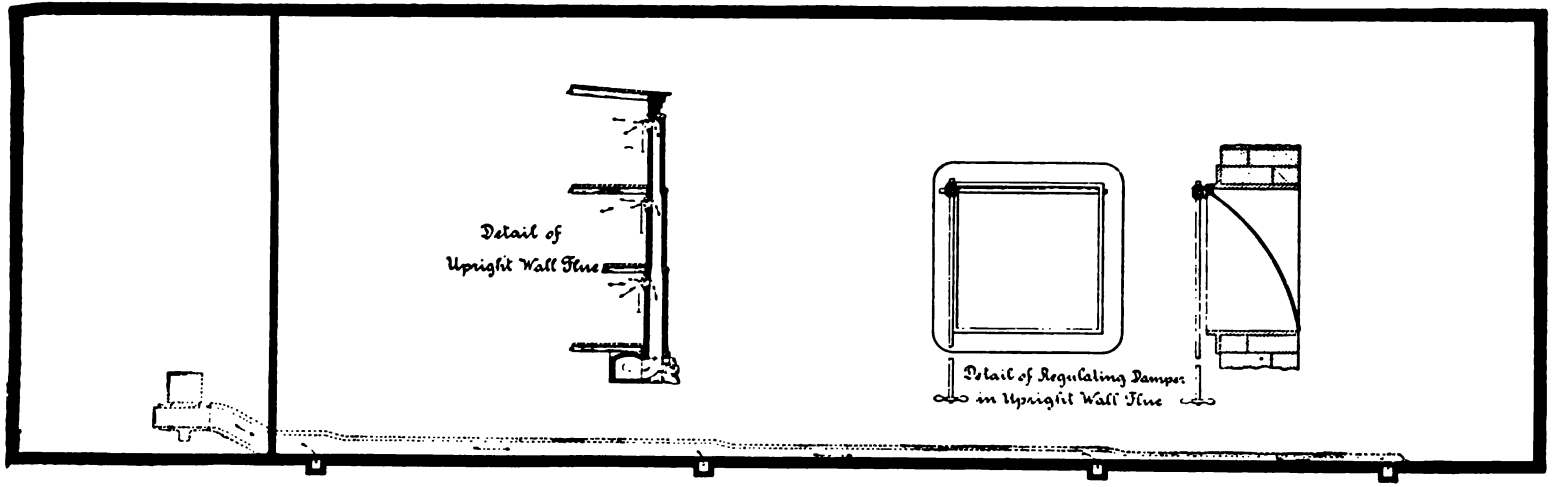
The distribution of the air is complete, and independent of all adverse conditions; a uniform temperature is secured in all parts of the building, north, south, east or west, both at floor and ceiling. In the case of direct radiation, the temperature

will vary in different parts of the room, — as a rule, being highest where the steam enters the coils. This difference is all the more marked between the top and bottom of the room when the pipes are overhead.

At the Globe Yarn Mill No. 1, which is heated by overhead steam piping, it has been noted by the superintendent, Mr. Sanford, that the thermometer showed a variation of from five to seven degrees between the north and south end of the building, which difference he attributes to the condensation in the long circulations.

In Globe Yarn Mill No. 2, which is heated by the Sturtevant system, he states that there is no perceptible variation in temperature between the two ends of the mill, and very little between the top and bottom of the room. By way of explanation, it is well to state here that Globe Yarn Mills Nos. 1 and 2 are located in the same position relatively to the points of the compass, — that is, very nearly north and south. Both are about the same size, and have the same exposure, the advantage being in favor of Mill No. 1, which is sheltered to some extent and protected from north-west winds by Mill No. 2. The steam admission to the system in each mill is at relatively the same point; that is, the south end. Both mills are about 300 feet long and 100 feet wide, and the cubic contents of Mill No. 1 is 1,103,852 cubic feet, while that of No. 2 is 1,316,520 cubic feet. Plate I. shows the ground plan of the Globe Yarn Mill No. 2, with the location of the heating apparatus and the arrangement of the flues. The apparatus is similar to that shown in Fig. 1, and located in the south-east corner of the basement. The fan wheel is eight feet diameter and five feet wide, and is driven by an 8 by 12 direct connected engine. Steam is taken from the receiver of a compound engine, and the exhaust steam from the fan engine is utilized in a portion of the heater. The maximum speed of the fan is 150 revolutions, at which speed about 70,000 cubic feet of air is delivered, changing the air in the mill once in every twenty minutes.

The main air duct, which is five feet square, is built of brick,



Application of Sturtevant System
in
Globe Yarn Mill, No: 2.
Fall River Mass.

the wall of the mill forming one side. There are four vertical flues; each connect with this main duct, at varying intervals of sixty to eighty feet, and run up in the outside wall of the mill. The openings on each floor are near the ceiling, and twenty inches square, the flow of air being regulated by dampers. The damper shown on the plate is the design of Mr. Wm. T. Henry, the architect, and is an excellent device for pilaster flues.

It will be noted that these flues are not built into the wall, but in outside pilasters, the walls of the mill having been built before it was decided to adopt this system of heating.

Perhaps there is no better place to state, that, at the time Mr. Henry advised Mr. Sanford to adopt this system of heating, there was no mill in Fall River which had the Sturtevant system in use; and there was all the more hesitancy about adopting the system, on the ground that their work was to be the spinning of fine yarns, the numbers running up to 140, and it was feared that the circulation of large volumes of air might cause breakage. We speak of this to allay any prejudice which may be entertained respecting the velocity with which the air enters the rooms.

The maximum speed of the fan causes the air to leave the tips of the blades of the wheel with a velocity of about one mile per minute, which velocity represents a pressure of one ounce to the square inch, or a water pressure of one and three-quarter inches. This velocity is reduced by enlargement of flues fifty to seventy-five per cent., dependent upon size and length; so that the water gauge would register, at outlets into the mill, from three-eighths to one-eighth of an inch of water, representing a velocity of from 2,600 to 1,400 feet per minute, the pressure of air varying directly as the square of the velocity. These velocities are understood to be registered in the outlet flue, where it opens into the room, and do not represent the velocity of the air currents in the room; as the air, on escaping into the room, immediately expands, and the currents are not perceptible except directly in front of the outlets.

Mr. Clark, the treasurer of the Clark (O N T) Thread Mills, where we understand the finest numbers in the country are spun, investigated this subject very carefully before adopting

the system in their new mills, and was so impressed with its advantages that it was introduced after the mills were erected, at greater expense than would have otherwise been required, it being necessary to use metal flues on the inside of the mill walls. The arrangement of these flues is shown by Plate II.

In this case, the metal flues (of galvanized iron) were rectangular in form, and attached directly to the walls. In order to maintain sufficient flue area, and yet avoid projecting too far into the room, it was necessary to divide the flues, and pass them up on either side of the floor girders. Each flue furnishes air for a single floor only; and, as there are five floors, every fifth flue goes to the same floor. The various details explain themselves. The apparatus shown on Plate III. is of the duplex type, which, in a slightly changed form, is illustrated in Plate VI., and described in connection therewith.

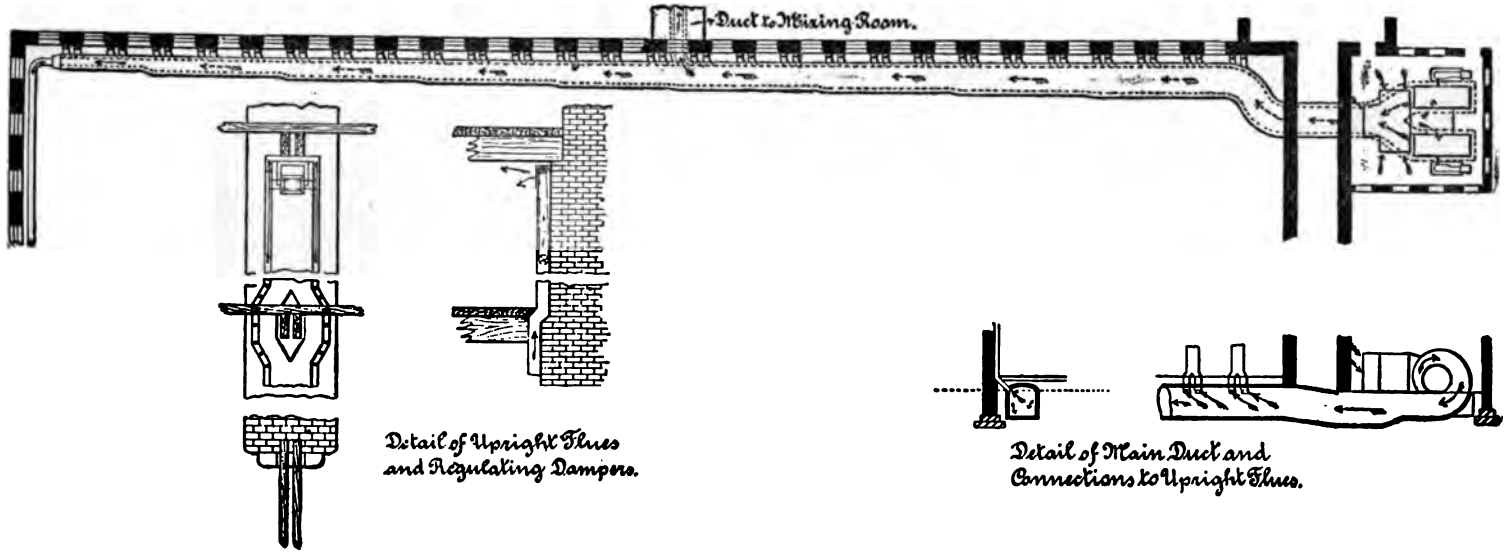
Referring again to the uniform distribution of the heat, we present, by the courtesy of Mr. Parker, the following figures (Table No. 1), taken at random from a record kept at the west weave shed of the Pacific Mills, where the Sturtevant system has been used the past two winters.

TABLE No. 1.

Temperature and Humidity in West Weave Shed, Pacific Mills, Lawrence, Mass.

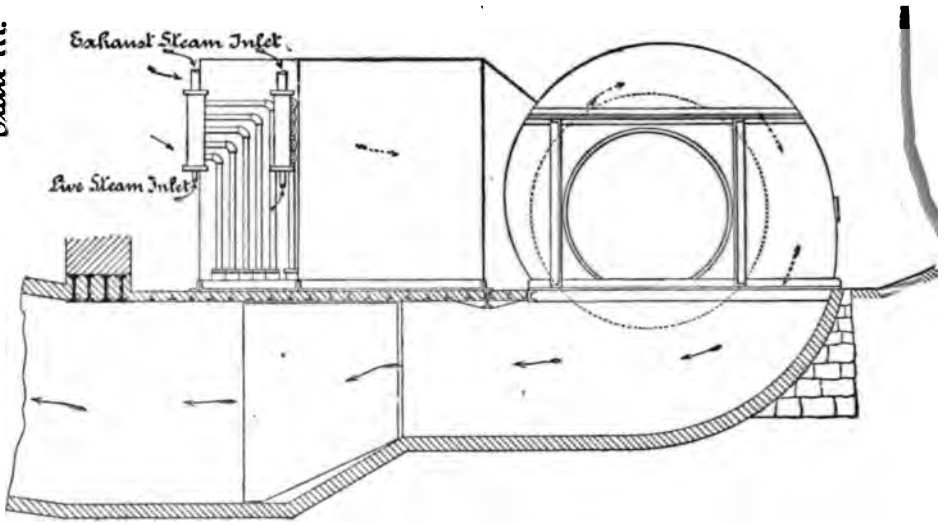
Date.	Time.	Temperature.					Humidity.
		East End.	Middle.			West End.	
			Floor.	Head High.	Ceiling.		
1889.		Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Per cent.
Feb. 7, .	9.15 A.M.	70	70	70	71	68	65
Feb. 7, .	1.15 P.M.	68	69	68	70	66	64
Feb 7, .	6.15 P.M.	70	71	71	72	66	66
Feb. 8, .	6.45 A.M.	70	69	71	73	66	61
Feb. 8, .	2.45 P.M.	73	74	75	76	72	68
Feb. 9, .	7.25 A.M.	70	69	71	72	66	75
Feb. 11, .	10.30 A.M.	68	68	69	68	68	75
Feb. 11, .	5.30 P.M.	72	72	73	72	69	63
Average,.		70.12	70.25	72.25	71.75	67.64	67.12

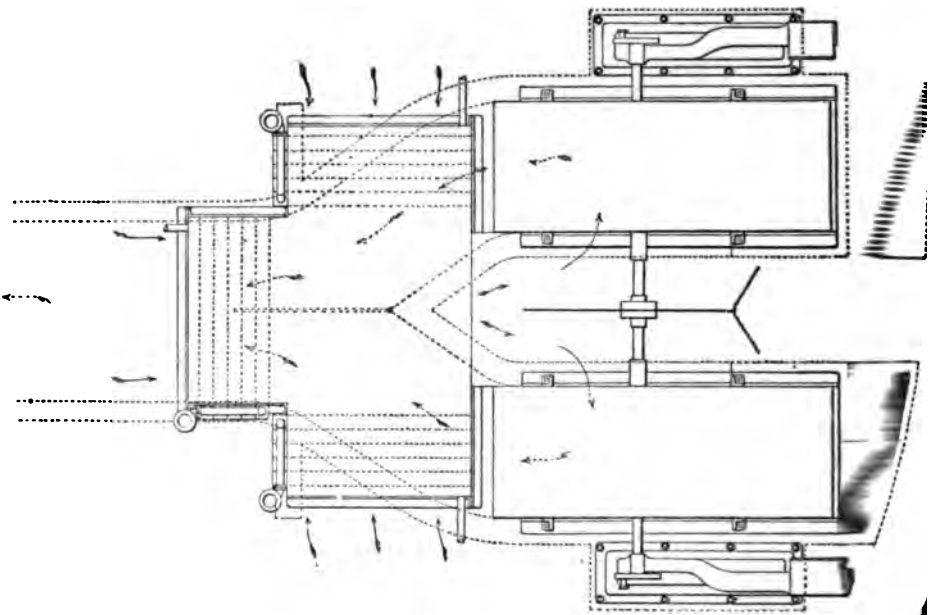
Plate III



Application of Sturtevant System
in
Clark (O.N.T.) Thread Mill, No. 3.
Kearney, N.J.

Plate III.





Sturtevant Heating, Ventilating and Moistening Apparatus
in
Clark (O.N.T.) Thread Mill No: 3
Kearney N.J.

The slight variations of temperature which exist between the east and west ends are accounted for by the fact that at the east end, on the first floor of the mill, are located the engine and dynamo rooms; adjacent to the east end is the large chimney, and directly underneath, in the basement, is the heating apparatus. With these conditions, it is remarkable that so little difference exists. The mill is 440 feet long by 70 feet wide, with two stories and a basement; the flues are constructed upon the south side of the mill, five in number, and average 100 feet apart. The canal runs along the north side of the mill, and the west end and north side are exposed to prevailing winds from the Merrimac. It can be safely said that hardly a more exposed location can be found in Lawrence; yet, with these adverse conditions, this mill, with 800,000 cubic feet of space, besides the basement, which is kept comfortable, is heated uniformly, so that there is practically no variation in temperature between the top, bottom and sides of the mill. By way of further explanation, it may be stated that the coil of pipe or heater contains 4,042 lineal feet of one-inch pipe, and the fan wheel is only six feet in diameter and three and a half feet wide, and is driven by a direct connected 6 by 9 vertical engine, the entire apparatus and the arrangement of the flues being very similar to that shown in Plate I.

The apparatus is located in the basement, near the northeast corner. The air duct, which is underground, leads to the south side, and then alongside the foundation wall, where it communicates with the vertical flues in the wall of the mill. The openings from these flues into the two floors are of Mr. Parker's design, of the shape shown on Plate V., and having an area of 172 square inches at the point where the air is delivered into the room, or 2.43 square inches of outlet to each 1,000 cubic feet of space.

The steam supply for the heater is taken from the receiver of a compound engine, at a pressure of from five to eight pounds; and the speed of the fan never exceeds 250 revolutions, this being regulated by the engineer, according to the

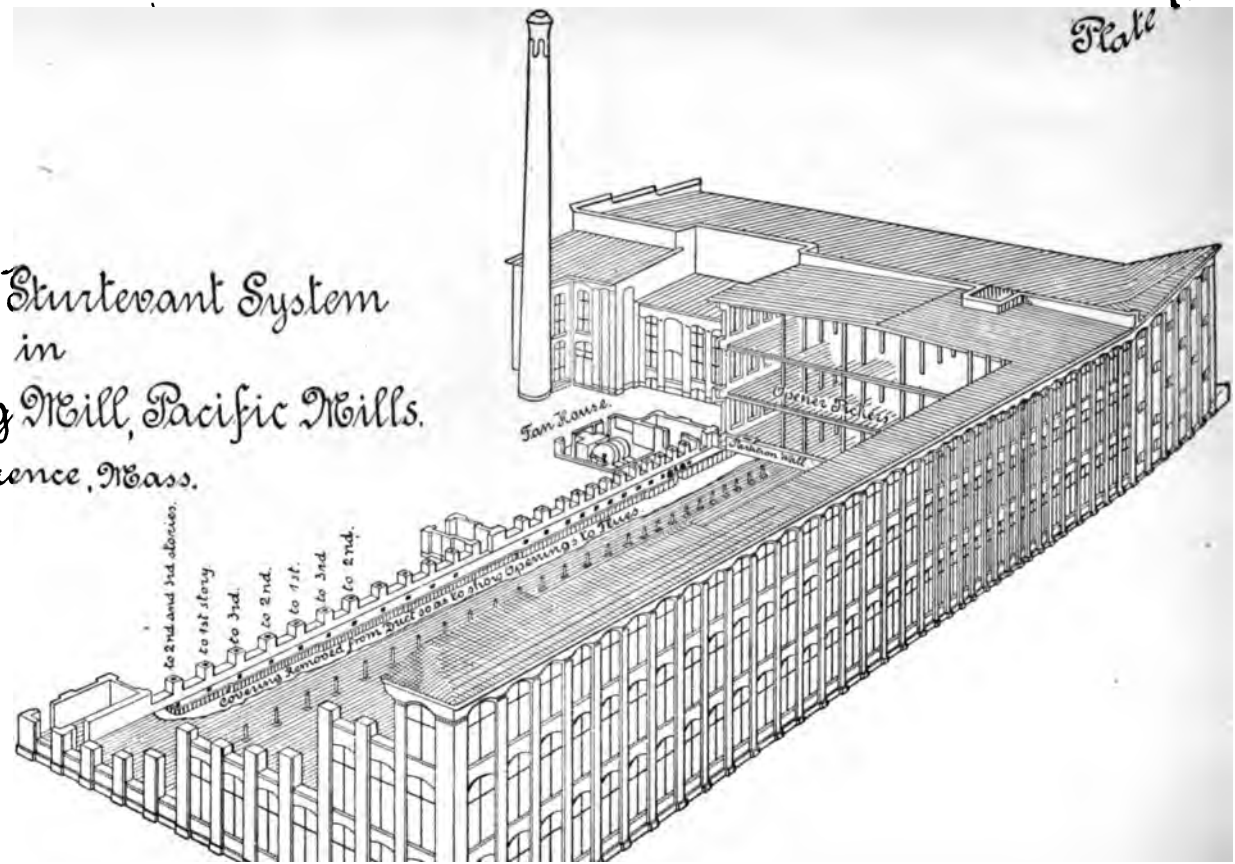
weather. The exhaust steam from the fan engine is, of course, utilized in a portion of the heater coil.

In the mills referred to above, it will be noticed that the air is admitted on the east side of the Globe Yarn Mill No. 2, and the south side of the Pacific west weave shed, that is, on the warmer side; and also that the outlets are from 60 to 100 feet apart. This wide separation of outlets is not prejudicial to an equal distribution of air and the maintenance of a uniform temperature. In both mills instanced, the walls were up before it was decided to adopt this system, which rendered it necessary to build the flues in pilasters upon the outside walls. In the case of the Clark (O N T) Thread Mill, the flues to each individual floor were placed 52½ feet apart, as a larger flue could not be located on the inside walls, and of necessity the flues were placed upon the west side of the spinning and on the east side of the thread mill. And, in the case of the new Pacific Spinning Mill (represented in Plate IV.), where the system was decided upon before the building was erected, smaller flues were built in the east wall, between the windows, at a distance apart, for the same floor, varying from 30 to 40 feet, according to the bays. This did away with the necessity of outside pilasters, and provided individual flues for each floor, which should result in a still more uniform distribution of the air, if such were possible.

We can instance cases, as with the Clark Spinning Mill, where the air has been allowed to enter on the colder side of the mill, and equally as good results were secured as in the cases where the air has been admitted on the warmer side; and we are not prepared to say that it makes any great difference upon which side of the mill the air is admitted. However, we favor blowing towards the colder side, because proper direction is thereby given to the entire volume of air, which has the effect of neutralizing the action of cold winds upon the exposed side of the mill, and also sets up a natural downward circulation of the air by the cooling action of the colder wall. The air should always be admitted near the ceiling, at least above the heads of the operatives.

Plate IV.

Application of Sturtevant System in New Spinning Mill, Pacific Mills. Lawrence, Mass.



As was intimated in the introduction, the ventilation of a textile mill presents two aspects — one from the humanitarian stand-point, and the other that of the corporation seeking a monetary return. At first thought, it might be supposed that the monetary return would be more imaginary than real. However, we think we can show that such is not altogether the case. We cannot present in this connection any data taken from textile mills bearing upon this point; but we have data from manufactories in other lines of work which should be applicable. A shoe manufacturer, who displaced direct radiation with the Sturtevant system, asserts that, in that portion of his factory where a large number of girls were employed at sewing machines, from ten to fifteen per cent. more work was turned out per day, and there was a much smaller per cent. of absentees. This result was brought about by the invigorating effect of a constant renewal of the air.

To cite another case, from notes on "Heating and Ventilation," by Prof. S. H. Woodbridge of the Massachusetts Institute of Technology, he states, that, since the employees of the Pension Bureau at Washington have been quartered in the new pension building, which is ventilated by the blower system, under the supervision of Gen. M. C. Meigs, U. S. A., the time lost by sickness for one year was 10,114 days, against 18,136 days under the previous conditions, with a smaller total force. You may say that these are not parallel cases, and consequently are not to the point. However, they are applicable, so far as they show that good ventilation will pay in any place where there is a large number of operatives, and the work is confining. We know that these conditions exist in every textile mill. Facts are continually showing, that, for mercenary reasons alone, it is advantageous to provide sufficient ventilation for all classes of operatives; although, as a rule, no provision whatever has been made for the proper renewal of the air. It is not proposed to read a lecture, in this paper, on the humanitarian aspect of the case, — for the State Board of Inspectors, acting under the statute laws of our Commonwealth, will do this if occasion demands. The neces-

sity of a better sanitary condition in a large number of our mills is apparent, and is receiving the attention of the proper authorities. The time is at hand when the question of ventilation will be considered as much as that of heating, and manufacturers will be required to supply the requisite quantity of fresh air to all operatives.

The best methods of securing the desired results are being investigated. There are two systems, — that by natural and that by mechanical means. The natural method for changing the air is by the introduction of wall flues with inlets from the various rooms. While such a system may be better than none, yet, as it requires a difference in the temperature of the air inside and outside of the building to create any draft, it always fails in summer, when it is most necessary. The next step in natural ventilation consists in placing a steam coil or gas jet within the flue, to create a current. It can be readily shown that this is one of the most expensive methods of moving air, for its movement is due solely to its levity. The steam thus expended in increasing the temperature could be much more economically expended in developing the power for driving a fan. Calculation will show, as Professor Woodbridge states, that, "among the many devices for the movement of air through channels, none are so economical of power and convenient in use as the fan." And Robert Briggs, whose large experience in practical ventilation and heating lends great weight to his words, asserts that "no other method than that of impelling air by a direct means, with a fan, is equally independent of accidental natural conditions, equally efficient for a desired result, or equally controllable to suit the demands of those who are ventilated."

Mr. Sanford, in speaking of the ventilation of Globe Yarn Mill No. 2, said, "The State inspectors have told me that our No. 2 Mill was one of the best-ventilated buildings in the State, and not one school-house in ten contained such good air for breathing purposes." He also states, "We also find a great benefit from the system in summer, by introducing a spray of water at the outlet of the fan. Our No. 2 Mill is kept from

four to six degrees lower in temperature than No. 1. This enables us to keep our windows closed at the bottom in No. 2 Mill, and we get clear of the lower draft across our work, which is a great advantage in fine spinning."

The friction of quick running machinery and the excessive window surface render a mill very hot and oppressive in the summer months. The temperature of a mill exposed to the sun reaches in many instances ninety to one hundred degrees Fahr. This can be reduced by the Sturtevant system from five to ten degrees, the cost of running a fan for cooling purposes alone being inconsiderable, compared with the advantages gained by the additional amount of work per operative. Some mills have adopted the exhaust method, by placing disc fans in windows at each end of the mill. This does not have the effect of cooling the air, for the air drawn in at the open windows is practically as warm as the air expelled. The Sturtevant is the plenum method, which puts a plus condition upon the inside of the building, and causes all currents to take an outward direction.

In reference to regulating the humidity of the air, we have stated that it was not in the range of this paper to discuss the advantages of moistening the air in cotton mills. We take it as an accepted fact that a high and constant humidity in the spinning of yarns and in weaving is necessary. You are all undoubtedly more or less familiar with the Garland apparatus, and have read the admirable treatise of Mr. Garland upon the subject. We suppose that the Garland apparatus has heretofore been accepted as the most modern and the best device in the market, and we know that it has been largely adopted. This apparatus utilizes the principle of an atomizer, and calls for an extended circulation of water and air pipes through the mill, together with a water tank and filtering device. This complication of parts and elaborate arrangement offers all the disadvantages of overhead steam pipes, in being the receptacle of dust and lint, of danger from damage by leakage, annoyance from leaky valves, and the breaking of glass air tips, with the care of the water tank and filtering devices, to say nothing

of the cost of running the air pump. The first cost is necessarily great, and the results are by no means satisfactory, since some of the same objections that are offered to steam pots and other devices are applicable here, in that the moisture is not uniformly distributed, and the relative humidity will vary with the location of the atomizer. Our attention was called two or three years ago to a moistening device invented, we believe, by Mr. J. S. Ludlam of the Merrimac Manufacturing Company, in which a small blower driven at a high velocity was used to distribute moist air. This was a step in the right direction, and an improvement over the many different devices. Wherein the various moistening devices have failed, has been in that they have lost sight of the principle that the circulation of the air was indispensable. Undoubtedly the other systems put the requisite amount of moisture into the air; but the effect is local, and not general, due to lack of circulation of the air. The air is saturated, or nearly so, at the distributing points in these moistening systems, while, at points removed from the distributing centres, the air will be dry, or nearly so.

The cost of installation of any one of the modern and approved moistening systems calls for a large outlay for the plant itself. Mr. Sanford, of the Globe Yarn Mills, states that the Garland moistening plant at Mill No. 1 cost $2,800; and, from inquiries that we have made, we should say that this was as low a figure as could be obtained for the installation of any modern moistening system in a mill of this size. Of the cost of maintenance, Mr. Sanford says that, from Oct. 15, 1888, to March 15, 1889, 130 days (the device not being used on Sundays and very moist days), it required 58,500 pounds of coal to actuate the pump, to say nothing of repairs. At $5 a ton (2,240 pounds), this means an expense of $130.58 for six months, for coal. In addition to this, the system requires pure water, which had to be taken from the city main at a cost of $1 per month, which makes a total of $136.58 as the cost of maintenance for six months. The average temperature of the mill during this time was 72 degrees, and the average rela-

tive humidity was 62 per cent. (Huddleston's Hygrophants). He also states, "There were very many dry and windy days, when we could not get, in the No. 1 Mill, more than 56 per cent. saturation." For the same six months, the average humidity in No. 2 Mill, moistened by the Sturtevant system, was 65 per cent., with an average temperature of 78 degrees.

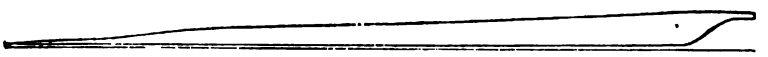
The only charge which can be made against the moistening of air in Mill No. 2, is the cost of the water. In conclusion, Mr. Sanford states: "In fact, with this system (the Sturtevant system) of heating, ventilating and moistening, we can get just what we want, and very quickly, at all times, for temperature and humidity; and we also have the advantage of keeping our relative humidity during the night at no extra cost, which is a great advantage in a fine spinning mill. With the Garland system, this would necessitate running the air pump, with its attention and expense for coal. Our No. 2 Mill is a fine spinning mill, our numbers running to 140; but we find no trouble in getting a breaking test above the English standard, and we know that our waste account is at a minimum."

The average relative humidity in Globe Yarn Mill No. 2 has been seen to be 65 per cent., with a temperature of 78 degrees; while in the Pacific west weave shed, with an average temperature of 70.5 degrees, the relative humidity was 67.12 per cent.; which gives good evidence as to the relative humidity considered to be most beneficial in the two mills. In either case the results were produced by the spray from a simple rose nozzle, attached to a half-inch pipe, spraying into the main duct at the mouth of the fan.

With the Sturtevant system, it costs practically nothing to regulate the humidity of the air during the season when it is necessary to heat the mill. In the summer months this cost is represented by the amount of water for moistening the air and by the power required to drive the fan, which is a small item, at the low speeds necessary to obtain the desired results. For instance, at the Globe Yarn Mill No. 2, they may run the fan during the summer months 50 revolutions per

minute, delivering 20,000 cubic feet of air per minute, with a consumption of power not exceeding two horse-power, which would represent (supposing the fan would be driven for moistening purposes for six months in the year) an expense of $50, considering that $50 is a fair estimate for the cost of a horse-power to a mill for a year. In addition to the moistening of the air during the summer months, it must not be overlooked that the large volume of moist fresh air thrown into the mill will reduce the temperature from five to ten degrees, do away with the necessity of raising the windows, and invigorate the operatives.

Right here it may be well to make a statement in regard to the amount of power consumed to drive fans. The laws which govern the movement of air by fans are not generally understood. The volume of air delivered varies directly with the speed, the pressure of air produced, as the square or second power of the speed, and the power consumed, as the cube or third power of the speed. It will be noted that economy in moving air with a fan is secured by moving the air at low velocities. Hence, for ventilating and heating, where little or no pressure is required, large fans are used, and the air ducts are proportionately large, in order to deliver large volumes at low velocities. Attention is called to an indicator card (Fig. 4) taken



Boiler Press, 115 lbs. Spring, 40 lbs. M. E. P., 6.3 lbs.

Fig. 4.

from a Sturtevant 12 by 18 engine, directly connected to a fan having a blast wheel 12 feet in diameter and 5 feet wide. It will be seen that the card is little more than a friction card, the admission of steam being regulated by the throttle, and that 2.65 horse-power represents not only the friction of the engine, but also the amount of power required to drive a blast wheel 12 feet in diameter at 41 revolutions per minute. The delivery of air at this speed is 30,000 cubic feet per minute, or 1,800,000 cubic feet per hour. The same fan and engine, operated at a maximum speed of 100 revolutions for mill heating, will indicate 20 horse-power.

It will of course be understood that the fan is never run at the maximum speed except in zero weather, and then only for a short time in the morning, the exhaust steam from the fan engine being used at all times in the heater; so that it is practically immaterial how much steam is required to drive the fan in winter weather, as it is well known that exhaust steam or low-pressure steam is practically as efficient for heating purposes as steam at sixty pounds. Low-pressure steam simply calls for a larger coil. We have indicated the amount of power required for driving the fan, and have shown that it is inconsiderable. In this connection we may say that the heaters are constructed with special reference to the use of exhaust or low-pressure steam, and the water of condensation is immediately removed and returned to the tank or boiler. The large condensation is due to the construction of the heater, and the impingement of large volumes of air directly upon the heating surfaces. We do not claim to get more heat units from the steam than it contains, but do claim to get all the useful heating effect into the air, and then distribute this heated air quickly and uniformly to the points where the heating is to be done. The economy of the Sturtevant system is in the rapid and uniform distribution of the heat. The heated air can be placed in the shortest time where it is needed.

As to the cost of the maintenance of the combined systems, the best opportunity offered for comparing the Sturtevant system with direct radiation, in conjunction with the Garland moistening system, is offered by Globe Yarn Mills Nos. 1 and 2, where an account of the coal burned for heating and moistening the two mills has been kept for the six months from Oct. 15, 1888, to March 15, 1889, — 151 days. In Mill No. 1, 375,600 pounds of coal were used. In Mill No. 2, with the Sturtevant system, 286,900 pounds were used; which is 88,700 pounds in favor of the Sturtevant system, to say nothing of the fact that the cubic contents of Mill No. 2 is 212,668 cubic feet more than Mill No. 1, an increase of nearly twenty per cent.; and also that Mill No. 1 is sheltered from

north-west winds by Mill No. 2, the north-west side of which is entirely exposed. Furthermore, the average temperature in No. 1 was 70 degrees, while that in No. 2 was 78 degrees. In Table No. 2, it will be noticed that the coal burned per 1,000 cubic feet of space was in the ratio of 100 pounds in Mill No. 1 to 64 pounds in Mill No. 2.

TABLE No. 2.

Comparative Cost and Running Expenses for Heating, Ventilating and Moistening Systems, Globe Yarn Mills, Numbers 1 and 2, from Oct. 15, 1888, to March 15, 1889.

COST OF INTRODUCTION.	No. 1.*	No. 2.†
First cost heating and moistening system,	$4,600 00	–
First cost heating, ventilating and moistening system,	–	$4,000 00
Cubic contents, cubic feet,	1,103,852	1,316,520
Average temperature,	70°	78°
Cost of system per 1,000 cubic feet,	$4 17	$3 04
Ratio,	100	73
	137	100
RUNNING EXPENSES.		
Coal burned for heating,	317,100 lbs.	–
Coal burned for moistening,	58,500 "	–
Coal burned for both heating and moistening,	375,600 "	–
Coal burned for heating, ventilating and moistening,	–	286,900 lbs.
Coal burned per 1,000 cubic feet,	340.26 lbs.	217.92 "
Ratio,	100	64
	156	100

* Overhead direct radiation and Garland moistening system.
† Sturtevant system of heating, ventilating and moistening.

It will also be seen from the table, that, eliminating the amount of coal required for operating the Garland system, the coal consumed for heating Mill No. 1 was 317,100 pounds, as against 286,900 pounds consumed in maintaining the entire Sturtevant system of heating, ventilating and moistening; a

difference of 30,200 pounds, or a total for heating alone of 287.26 pounds per 1,000 cubic feet in No. 1, and 217.92 pounds per 1,000 cubic feet in Mill No. 2, in the ratio of 100 to 70.9.

Not only was the heating and moistening in Mill No. 2 more perfect, but the ventilation was such as to excite the admiration of the State inspectors. These comparisons are particularly valuable, because the two mills are nearly of the same size, are located side by side, are used for the same class of work, and the advantage both in point of size and location is in favor of the mill heated by direct radiation. It is rare that an opportunity is offered to make such a comparison.

The results at the New Pacific Spinning Mill for the past winter, without any machinery in the mill, have been such that Mr. Parker remarked to the writer that he had little doubt but that the exhaust steam from the fan engines would be found sufficient to heat the mill except in zero weather.

Under date of Nov. 30, 1888, Mr. Parker writes us respecting the working of the heating apparatus in the west weave shed: "We have made no tests to compare the economy of this system with direct radiation, it being considered that, where so many persons were employed, the advantage derived from ventilation more than compensated for the possibly slightly increased cost. My impression is, however, that this method of heating is as cheap as by direct radiation. It is on account of the satisfactory working of this apparatus that we have given you an order for the plant for our new spinning mill."

The only fair comparison for economy of fuel which can be made between the Sturtevant system and that of direct radiation, is to put them on an equal basis; that is, with direct radiation, the air is constantly reheated over and over again, little or no provision being made for ventilation; hence the Sturtevant system, when compared for economy of coal consumption, should take its entire air supply from the mill. When this is done, there is no question as to the coal consumption. But the system does not contemplate taking the entire air supply from the mill, although a large portion may

be so taken without detriment to the breathing quality of the air. It should be borne in mind that the Sturtevant system is a plenum system, and that a plus condition in the building is secured; there is a slight pressure maintained in the room, and the direction of all currents is outward. This not only has the effect of preventing the entrance of cold air around the windows and doors, but causes an escape of air at these points, affording sufficient ventilation, the aggregate area of crevices around windows and doors in any room being surprisingly large. The leakage around an ordinary window is, on the authority of Dr. Billings, eight cubic feet per minute; so that it will be readily seen that the large window surface in textile mills affords abundant opportunity for the escape of air in the Sturtevant system.

In the case of the Globe Yarn Mill No. 2, the apparatus is located in the basement, and the supply of air is taken from the basement, which opens into the mill through the shafts for elevator and stairs. Windows in the basement are opened to obtain a suitable supply of fresh air from outside. It will be seen from Plate IV., representing the New Pacific Spinning Mill, that the tower containing the stairs with its openings to each floor leads into the room containing the heating apparatus. Fresh air is taken into the fan house by simply opening outside windows.

Generally speaking, the more indirect the system the greater the first cost; but the cost of any system will vary with the thoroughness of the installation of the plant. A system of direct radiation may be made more or less expensive, according to whether it is large or small for requirements, the thoroughness of installation, and the character of material and workmanship.

The same may be said of the Sturtevant system; the cost of installation will vary considerably under different conditions.

1. Whether high or low pressure steam is used; the use of low-pressure steam necessitating, as has been previously stated, approximately double the amount of pipe used with high-pressure steam.

2. Whether the apparatus is duplex or single, in the former case two fans and two engines being used.

3. Whether the flues are built into the walls, or the air is distributed by metal pipes.

4. The purpose for which the building is used.

5. Exposure, window surface and construction of building.

The plant at the New Pacific Spinning Mill is without doubt the most complete of any system in the country. The apparatus shown in Plate VI. is known as a duplex; the two fans, which are each seven feet in diameter and four feet wide, are each driven by a 7 by 12 direct connected horizontal engine, and can be coupled together, so that they may be run independently or together, with both engines or a single engine. The coils are arranged in three groups, in the form of a hollow square. Plate V. shows the construction of the main flue and the flues in the wall. The main flue is constructed of brick, the mill wall forming one side, the other being a twelve-inch wall with air space. The bottom is brick, cemented, while the top is of corrugated iron, covered with brick in cement. The flues in the wall are lined with fire clay flue lining, eleven inches by fourteen inches inside.

As will be seen from Plates IV. and V., there are individual flues for each floor, located thirty to forty feet apart, in the piers between the windows. The opening from the flue into the room is the same as used at the west weave shed.

The thoroughness with which this plant is installed reflects great credit upon Mr. W. E. Parker, the agent, and the architect, Mr. F. P. Sheldon of Providence. Mr. Parker, appreciating the advantages offered by the system, spared no expense to install it properly. As the contracts for building the mill included the small building for the apparatus, together with the flues, it is impossible to get at the cost. However, it may be stated, on the authority of Mr. Wm. T. Henry, the leading mill architect of Fall River, that plain flues in the wall cause no additional expense, the fewer brick required compensating for the additional labor. This is where the flues are put up in pilasters in the outside walls, and are plastered on the

Plate V.

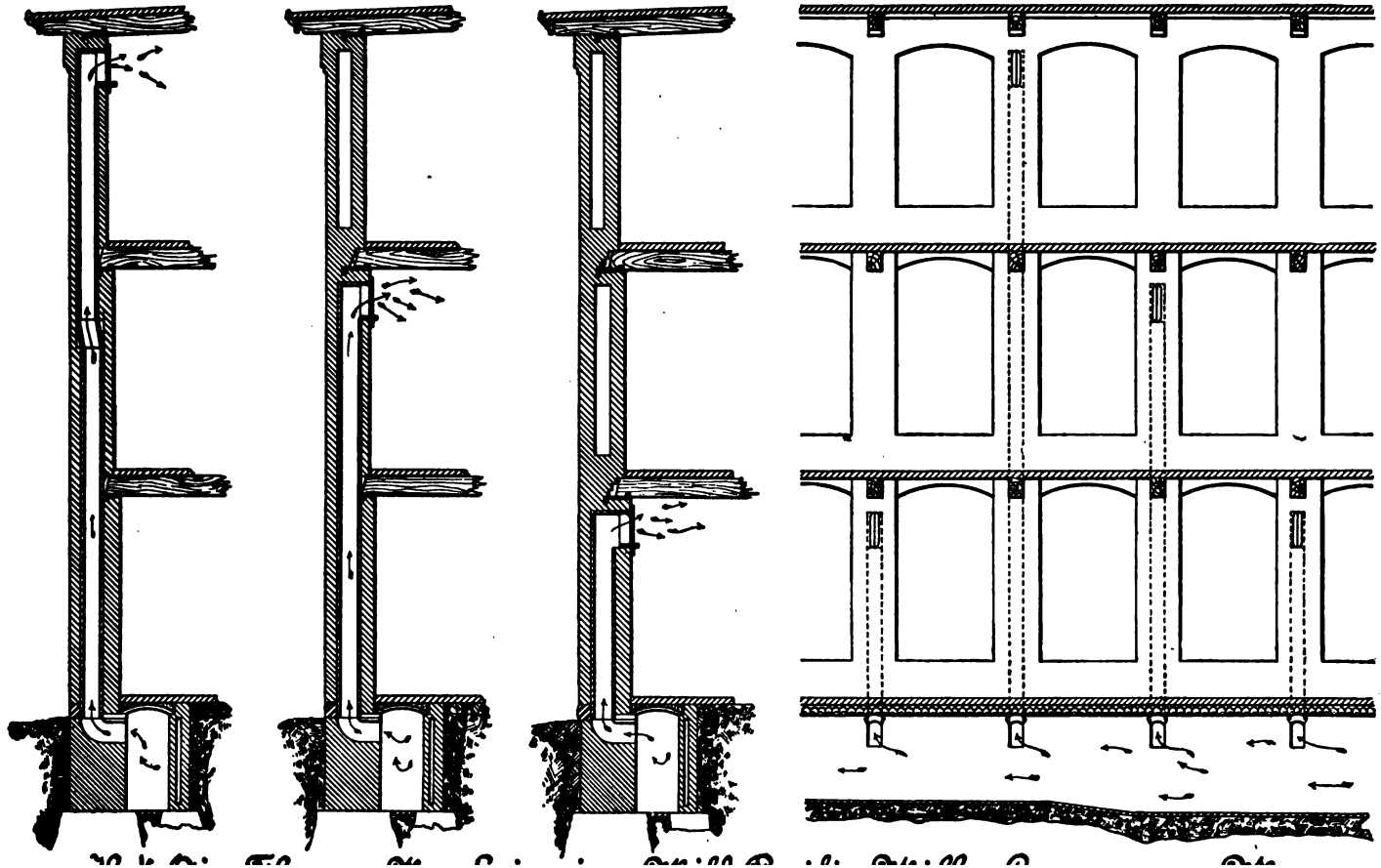
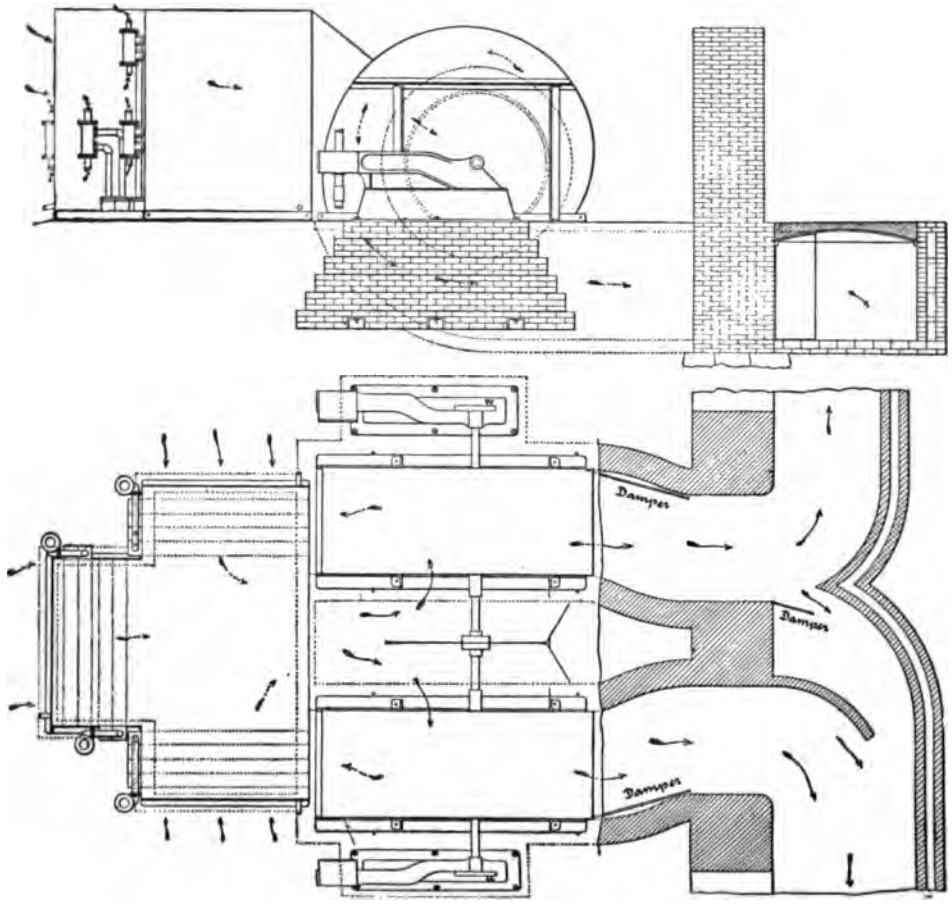
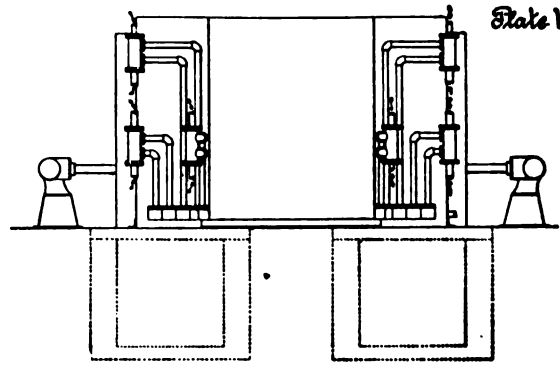


Plate N.





Sturtevant Heating, Ventilating
and Moistening Apparatus
in
New Spinning Mill, Pacific Mills.
Lawrence, Mass.

inside, no flue linings being used. The cost of the main duct is not heavy, as one side is formed by the foundation wall, and the top is covered by corrugated iron, as at the Pacific Mill, or plastered on wire netting and covered with plank. This latter plan was adopted in the case of the Globe Yarn Mill No. 2, where the cost is given by Mr. Sanford as being $4,000 for the fan, engine, heater, return water apparatus, steam connections, main flue in basement, pilaster flues, dampers, etc. He also states that the cost of direct radiation in Mill No. 1 was $1,800. There are three runs of pipe around each side of the mill, near the ceiling. Add to this the cost of the Garland moistening plant, $2,800, and you have a total cost of $4,600 for the heating and moistening plant in Mill No. 1. From Table No. 2 it will be seen that the first cost per 1,000 cubic feet is as 100 to 73 in favor of Mill No. 2.

As to comparison of cost of repairs between direct radiation and the Sturtevant system, we think it will be readily conceded to be in favor of the latter. Much could be said pro and con; but the character of the machinery, its few parts, slow speeds of engine and fan, the sectional construction of the heater, the lack of complication of valves, concentration of plant at one point, and the fact that it is under the care of one man, are greatly in its favor.

As yet nothing has been said regarding the provision afforded by the Sturtevant system for heating and ventilating the troublesome picker house. As the pickers are constantly removing large volumes of air from the room, which must be supplied from some source, this system, supplying warm air to the room in large quantities, performs the double duty of warming the room and neutralizing the disagreeable effects of these exhausters. We anticipate wonderful results from this alone, and there is no doubt that the Sturtevant system will thoroughly ventilate and heat a picker house, something which has been considered heretofore well-nigh impossible. We call attention to Plate V., showing that in the New Pacific Spinning Mill a large flue is led into the picker house,

of sufficient size to supply the requisite amount of air for the picker fans.

As accessories to its main work of heating, ventilating and moistening, the apparatus can be used for drying cotton, yarns, cloth and wool, and also for removing steam from dye-houses. It is well known that there is no method so effective for clearing a dye-house of steam as blasting in a large volume of warm air, which absorbs the moisture in the air and carries it out through ventilators.

In conclusion, we must acknowledge that the subject has been treated superficially, and that much more might be said respecting its details and advantages. It should be borne in mind that heating, ventilating and moistening co-exist in this system; and that, to produce any one or all of these three requisite conditions to a perfect system, one and the same apparatus is used.

The apparatus is free from complicated mechanism, easy to regulate, and most efficient in results.

It compares favorably in first cost, cost of maintenance and repairs, with other systems. It surpasses all other systems in results secured.

It eliminates all steam pipe from the mill.

Fire risk is reduced to a minimum. It is to all other systems in point of fire risk what the slow-burning construction mill is to the old-style mill architecture.

It combines, in addition to the essential features of heating, ventilating and moistening, the other useful accessories of drying, clearing steam from dye-houses, and neutralizing the effect of fans in picker houses. It heats the mill uniformly at top, bottom and sides. The ventilation is perfect; the operatives are invigorated. The humidity of the air in every part of the room may be perfectly regulated. All tanks, filtering devices and systems of steam, air and water piping, with attendant valves, are done away with.

The Sturtevant system is the system of the future. Its adaptability is not confined to any class of buildings. It is

particularly applicable to school-houses, churches, theatres and all halls of audience. It only awaits the development of the electric motor, or some other means of driving the fan, to extend its field to the heating and ventilating of dwellings.

A MEMBER. I would like to ask Mr. Foss, in regard to the horizontal flues, which he considers the better or cheaper,— the metallic flues suspended from above, enclosed in a box, packed with sawdust or tan-bark, or a vault built up from the basement with brick?

Mr. FOSS. I should say, put them in brick, and, in case of mills, let the inside of the wall form one side of the flue. In many cases the basement floor of the mill will constitute the bottom of the flue.

On motion of Mr. BORDEN of Fall River, it was

Voted, That the board of directors be authorized to lay an assessment on the members of the Association, to defray the expenses of the ensuing year, not exceeding ten dollars each, as provided in the by-laws.

The PRESIDENT. The next paper on the programme is the "Barnard Vacuum System for Circulating Steam in Heating and Drying Coils," by Mr. CHARLES F. TARBELL of Boston.

THE BARNARD VACUUM SYSTEM

FOR

CIRCULATING STEAM IN HEATING AND DRYING COILS.

By CHARLES F. TARBELL, Boston, Mass.

The object of this paper is to briefly describe the application of the vacuum system to existing steam-heating plants, to draft the steam through coils, radiators, drying cylinders, etc.; also to show the efficiency of such system, as compared with the usual method of forcing steam through coils by more or less pressure, as generally practised, either a back pressure on the piston of the engine, if exhaust steam, or some fraction of the boiler pressure, if live steam is used.

Some of the disadvantages incident to using steam under pressure may be summarized thus: —

Liability of the condense water in pipes to freeze.

Imperfect circulation of steam in most cases.

An additional duty on the engine or boiler, or both.

The large (and oftentimes unnecessary) expense for fuel.

These disadvantages exist to a greater or less extent in every pressure system.

The accumulation of water is liable to occur in all pressure systems, as it is quite impossible to entirely free the horizontal pipes from water, which necessarily accumulates by condensation after the steam has been shut off. If exposed, such pipes may, and often do, freeze, causing expense, loss of time, and trouble in making repairs.

Many steam-heating plants have a poor circulation, in whol or in part, from various causes, requiring considerable pres ure to force steam through the pipes. One of the princi

obstructions to the circulation of steam under pressure is the accumulation of air — always liberated from steam when condensed into water — and the accumulation of water in the pipes; great difficulty is experienced in many heating plants to properly discharge such air and water. When such conditions do exist, the coils are slow to heat, as the steam can only follow the air and water in its course towards the discharging point; and, until the steam is actually present, the pipes must remain cold. It is confined air and water that causes "water-hammering," sometimes breaking the pipes from their fastenings.

Many buildings are heated by live steam, sometimes by extra or special boilers, and the exhaust steam allowed to escape to the atmosphere, — available heat thrown away.

Some of the reasons sometimes given for not using exhaust steam are: that the heating pipes are not adapted to the use of exhaust steam; that the engine has all that it can do, without loading it further by back pressure; and occasionally, from the impression that the exhaust is deficient in temperature, and would not answer the purpose.

Theoretically, live steam is two or three per cent. more efficient than exhaust; but it would require a more delicate instrument than the thermometer to show any difference in the temperature of a room heated by exhaust steam at atmospheric pressure, properly circulated, and the same room heated by live steam, using the same coils or radiators.

When exhaust steam is not available, it is decidedly economical to reduce live steam from boilers to nearly atmospheric pressure, and draft such low-pressure steam through heating coils and radiators, in preference to circulating the live steam by considerable initial pressure. When so used by the vacuum process, the circulation is vastly improved, and the sometimes objectionable "snapping" in pipes entirely disappears. This last feature alone will commend the vacuum system to all, and justify its application to many buildings.

It is not always definitely known what it costs to heat a mill or building by steam, as it is difficult to separate the cost of

steam for heating from the cost of steam for power, either in the case of heating by live steam from the boilers or exhaust steam from the engine.

Steam users know the difference between the coal consumed in July and the coal used in January; the difference is generally accepted as the cost of heating. When exhaust steam is employed for heating, it is as a rule used under some back pressure. Such use is more economical than to use live steam from the boiler; but, nevertheless, back pressure costs money, and very often lessens the capacity of the engine to an extent that necessitates forcing the boilers, and frequently forcing the engines, both of which are expensive and detrimental.

The vacuum or suction system is entirely free from the faults and expense of the pressure systems, for the reason that the conditions of circulation are reversed.

The partial vacuum operating the system is applied at the extreme or tail end of the heating coils, and exerts the greatest suction at such points; this suction is gradually lessened as it approaches the source of steam supply, but is always sufficient to draft the steam.

It is immaterial to the circulation of steam in pipes, whether an initial pressure exists at the source, or not; if the conditions are such that some pressure above the atmosphere does exist, it is no objection, but is of no benefit, as the partial vacuum will draw the steam through the pipes faster than it will circulate under any conditions of pressure, except in the case of the return or waste pipes being freely open to the atmosphere, which is not admissible where fuel costs money.

The vacuum at the tail end freely draws the air and water from the pipes; and, those obstacles not existing to retard the circulation of steam, it follows that the steam will freely and quickly flow from its source towards the vacuum end of the apparatus.

Whatever leaks may occur are towards the interior of the pipes, by reason of the partial vacuum within; consequently, water is not liable to drip from a leaky valve or fitting, causing trouble and damage.

For ordinary heating and drying purposes exhaust steam is fully equal to live steam; it is well known that the latent heat in steam is equally as valuable for such purposes as is the sensible heat, and also that the sum of sensible and latent heat is practically the same for all pressures of steam as commonly used.

A long experience has abundantly proved that exhaust steam at atmospheric pressure is, by the vacuum system, freely circulated through ordinary steam-heating plants erected for live steam heating; as a rule, the only alteration made, if any, is to change the position of the terminus of the main return pipes, to adapt them to the vacuum system.

The vacuum system permits the combined use of live steam reduced to a low pressure and exhaust steam without back pressure, in the same pipes. The draft, due to the vacuum, draws the steam away from the engine, through the heating pipes, without any tendency of the live steam to flow back towards the engine through the exhaust pipe.

The vacuum system is equally effective on any type of coil or radiator, also for indirect coils, such as the Sturtevant warm air heating and ventilating system. Wherever steam is to be circulated in pipes, it will cause the steam to be circulated with better efficiency and greater rapidity than is possible by any pressure system.

It may be proper here to cite a case of a mill that was heated by both live and exhaust steam, — perhaps heated as economically and effectually as the average mill. Reference is had to the American Linen Company of Fall River, their No. 1 and 2 mills aggregating about 2,500,000 feet cubical contents, and having about 40,000 feet of one-inch pipe in coils. The exhaust steam was furnished by a Corliss engine, with a 32 by 54 inch cylinder, running at 65 revolutions; from 3 to 8 pounds back pressure was carried, according to the weather. Each pound of back pressure equalled fully 11 indicated horse-power, and the back pressure averaged at least 5 pounds, or, say, 55 indicated horse-power. This engine was so fully loaded, that during the heating season it became necessary to throw off

certain machines requiring this average of 55 horse-power, in order to enable the engine to maintain its speed under such back pressure. What the value of loss of product represented by these idle machines amounted to, is not known to the writer; but undoubtedly it was an important item.

The cost of the back pressure is easily figured. Assuming the engine ran ten hours per day, used three pounds of coal per indicated horse-power per hour, and coal cost $4.50 per gross ton, — we have 11 × 5 × 10 × 3 = 1,650 pounds coal, costing $3.30 per day; and, estimating 160 heating days per year, is 160 × $3.30 = $528, as the evident cost per year of the back pressure on this engine.

In addition to the exhaust steam, considerable live steam was used to supplement the exhaust, which in itself was insufficient under the old system. The quantity and value of this live steam could not be accurately determined, but it is believed to have been equal in volume and value to the exhaust steam.

Notwithstanding the combined use of live and exhaust steam, it was, under the old system, very difficult to heat some of the rooms for two or three hours in the morning in cold weather, owing to the difficulty of freeing the pipes from air and water. In the summer of 1886 the Barnard vacuum system was applied to the heating plant of these mills. Since its application, no back pressure has been carried on the engine, and no live steam used for heating purposes during working hours; the circulation in the coils was greatly improved, every room being thoroughly warmed at all hours, and in some cases the rooms were overheated; when, before the change was made, they were, under like conditions of time and temperature, too cold to be comfortable.

The water of condensation from heating coils should be pumped back to the boilers, as it is practically pure and at a high temperature.

If the cylinder oil in the exhaust steam or condensed water is objectionable, either on account of the possibility of the oil lodging in the heating pipes, or detrimental to the boilers when

used as feed-water, the oil can be separated from the steam by using an oil separator fixed in the main supply pipe.

Sufficient steam for heating a mill may be taken from the receiver of a compound condensing engine, without impairing the effectiveness of the engine, and also without a very material increase in the steam used by the engine per indicated horse-power per hour. Where compound engines are in use, and all the steam used by the engine is transmitted from the high-pressure to the low-pressure cylinder, and thence to the condenser, and live steam exclusively used for heating, the whole charged to the indicated horse-power of the engine, as is generally done, as compared with steam drafted from the engine receiver for heating or drying purposes, the whole charged to the engine as before, — the superior economy of the latter method will be very marked, for the reason that the steam has performed a large part of its work in the high-pressure cylinder, without impairing its value for heating; and, whatever difference is represented by such work, and the cost of live steam used exclusively for heating, as in the other case, is the difference of economy between the two systems. The economy of the steam used in the high-pressure cylinder does not depend to any great extent upon the point of cut-off in that cylinder within liberal limits (far greater than is the case with a simple or single cylinder engine); and, where receiver steam is used for heating, the cut-off should be enough later in the high-pressure cylinder to furnish the requisite steam for heating, and at the same time preserve a highly economical ratio of expansion in the two cylinders.

The above is based on the supposition that it was not intended by the engine builders to use receiver steam for heating, when the cylinders were proportioned for the power alone.

Quite a number of compound engines are in use, specially designed to furnish receiver steam for heating, drying, boiling, slashing, etc. The only difference in such design is a smaller ratio of cylinder areas; the greater the quantity of receiver steam to be used for extraneous purposes, the closer are the

respective diameters of the two (or more) cylinders. In practice, within the writer's personal experience, the differential areas of compound cylinders has varied anywhere from 2 to 1, to 4 to 1, according to the amount of receiver steam externally used. It will be seen, that, in case the areas of cylinders approach 3½ or 4 to 1, a later cut-off in the high-pressure cylinder, for an excess of receiver steam to be used for heating, is equivalent to a lesser differential area of cylinders; as in the case where the cylinders are specially designed for developing a given power, and furnishing a given quantity of receiver steam for use other than power.

The illustration accompanying this paper is an exhibit of the application of the Barnard system to either live or exhaust steam. The path of the steam is readily traced from the exhaust pipe of the engine to the feed-water heater, or from the boilers through reducing valve, thence to the heating coils, and by the return pipes to the hot-water tank, in which a partial vacuum is maintained by a condenser, as shown. The boiler feed-pump forces the returned water from the tank through the feed-water heater to the boilers, in the usual way. The water returned from heating coils is never sufficient for feeding the boilers, as all of the exhaust steam is seldom circulated through the heating coils, and losses occur in various ways. The return water from the coils is necessarily supplemented by cold water sufficient for feeding the boilers. It is this supplemental water that is usually circulated through the condenser, and is in all cases fully ample for the purpose. A live-steam connection is shown, which may be used to supplement the exhaust, if insufficient.

It will be noticed that this water in return tank is at a much higher temperature than normal, and is consequently more readily heated in the feed-water heater, and with less steam, than is the case with cold water entering the heater, resulting in a higher temperature to the feed-water, and more exhaust steam available for heating; for, in such case, less exhaust steam is required to heat the feed-water.

The Barnard vacuum system differs from those vacuum systems employing a large air pump, as follows: —

The Barnard system deals only with the vapor of the return water; such vapor represents but a very small fraction of the steam originally delivered to the heating coils, as almost the whole of such steam is condensed within the pipes by radiation and atmospheric condensation.

The small amount of steam returning with the water is condensed by the condenser, and such condensation of the vapor maintains a constant and steady vacuum in the tank; which in turn draws on the whole system of piping.

If the return water is not required for feeding the boilers, as shown above, it may be siphoned off to a race or sewer, or other use made of it.

As the vapor in tank to be condensed is very small, a comparatively small condenser and small air pump are employed. It is doubtful if the largest of steam plants would — with the Barnard system — require an independent air pump with a steam cylinder larger than 3 by 6 inches; and steam sufficient to move such pump at a speed of not to exceed fifty feet per minute would represent the cost of running such pump, keeping in mind the fact that the pump has absolutely no work to do other than to overcome its own friction, and lift perhaps ten gallons of water six inches high per hour.

The pump systems necessarily employ quite a large pump. Such pump must have ample capacity to draw and discharge all the hot water from the returns, and, in addition, create more or less vacuum by displacement of the air piston. As the vapor from the hot water tends to fill the air cylinder of such pump by expansion, it follows that the air cylinder must be of liberal proportions to accomplish its work; and it must have an ample steam cylinder, moving at a comparatively high speed, to do the work imposed upon it, and consuming considerable steam.

The type of condenser shown is one of several. The Barnard system embodies any type of condenser that may be best adapted to the conditions, and for the purpose of circulating steam through heating pipes. In some instances the condenser of a condensing engine on the premises has been used with

excellent results, and without at all impairing the engine vacuum, as demonstrated by both vacuum gauge and indicator card.

It is only necessary to understand the principles and advantages involved in the vacuum steam-heating system, to obtain for it a preference in all cases over any pressure system.

The PRESIDENT. The subject of the heating of mills has been presented to you in two papers. I should be very glad to have any member express his views.

Mr. C. J. H. WOODBURY. As two of the speakers who have furnished papers are not members of the Association, I beg to offer this resolution: —

Resolved, That the thanks of the New England Cotton Manufacturers' Association are tendered to Mr. W. S. Kelley of Lowell, Mass., for the paper on "Application of Electro-motive Power to Mill Work;" and to Mr. Eugene N. Foss of Boston, Mass., for his paper on the "Sturtevant System of Heating, Ventilating and Moistening Textile Manufactories," — both of these papers treating of matters of great importance to manufacturers.

The omission of any reference to the instructive paper read by Mr. Charles F. Tarbell is not in any sense a disparagement, but it does not appear that in this instance any formal thanks are necessary, as Mr. Tarbell is a member of the Association; because I understand it is one of the duties of the members to do all they can for the interests of the Association.

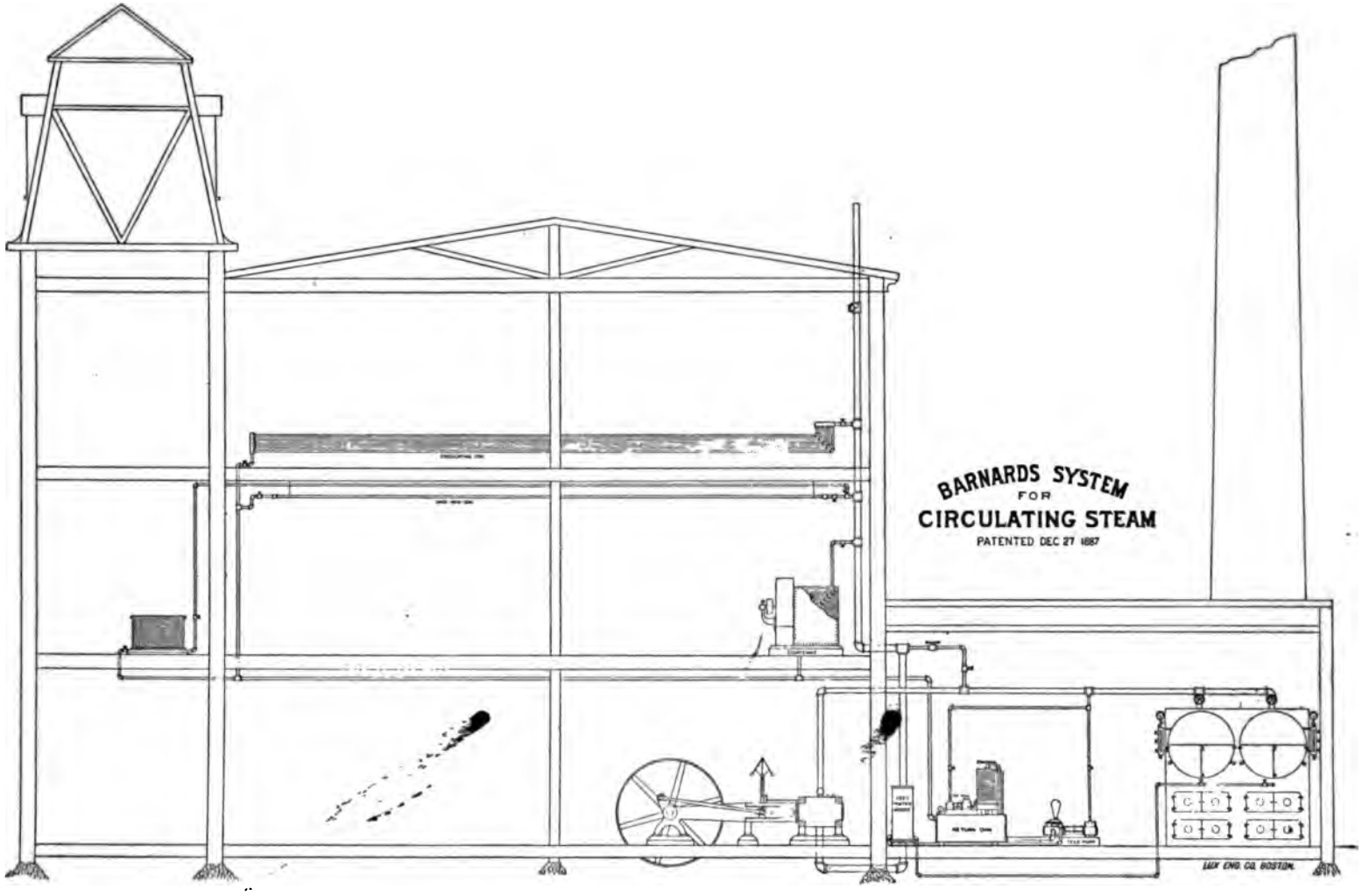
The PRESIDENT. The papers read to us have been admirably presented, and the one by Mr. Kelley of Lowell, while it presents his views clearly, is also written in fine style.

Mr. WOODBURY'S motion was carried.

Mr. WALKER. Although I am not a member of the Association, I would like to ask Mr. Tarbell whether the Barnard system removes the objectionable feature of the snapping of the pipe?

Mr. TARBELL. It removes it entirely. There is no snapping with the use of this system.

Adjourned.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